AIRCRAFT NUCLEAR PROPULSION PROGRAM

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY CONGRESS OF THE UNITED STATES

EIGHTY-SIXTH CONGRESS

FIRST SESSION

ON THE

AIRCRAFT NUCLEAR PROPULSION PROGRAM

JULY 23, 1959

Printed for the use of the Joint Committee on Atomic Energy

UNITED STATES
GOVERNMENT PRINTING OFFICE
44441 WASHINGTON : 1959

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THURSDAY, JULY 23, 1959

CONGRESS OF THE UNITED STATES,
SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10 a.m., in room 318, Senate Office Building, Hon. Melvin Price (chairman of the subcommittee) presiding.

Present: Representatives Price, Durham, Holifield, Van Zandt, Hosmer, Bates, and Westland; Senators Anderson (chairman of the Joint Committee), Gore, Jackson, Hickenlooper, Dworshak, and Aiken.

Also present: James T. Ramey, executive director; John T. Conway, assistant director; David R. Toll, staff counsel; Edward J. Bauser, technical adviser; G. Edwin Brown, Jr., Richard T. Lunger, professional staff members, Joint Committee on Atomic Energy.

Representative PRICE. The committee will come to order.

This morning the Research and Development Subcommittee of the Joint Committee on Atomic Energy is meeting for the first time in public session to receive testimony on the present status and future prospects of the aircraft nuclear propulsion program, or ANP program as it is commonly referred to.

The Joint Committee has held some 36 hearings on this subject over the past 11 years. These have all been in closed session at the request of the executive branch for reasons of national security.

This project has been underway since 1946, most of which time it has been under the joint auspices of the Defense Department and Atomic Energy Commission. During this period the program has been marked by many changes in its general orientation and in funding levels. It has also been marked by a lack of well defined objectives and by administrative indecision.

The result has been that the scientists and engineers doing the actual work in the field have not received any clear guidance as to what the specific aims of the program are and what direction they should apply their efforts. A particular difficulty, in this regard, has been the lack of any target dates for ground test and actual flight of a nuclear propulsion system.

The fact that there are today, 13 years after the project was initiated, no such dates in the program is mute testimony to the difficulties being faced by our hard working scientists and engineers in the field. It is indeed a tribute to these able and devoted men that they have continued to make steady technical progress in their work

and that major technical schedules have been met despite the advanced nature of the research and development work involved.

As I stated earlier this week, members of the committee have been distressed to learn that plans for a flight program for the nuclear propelled aircraft, which only a few weeks ago appeared to be headed for approval, are now being shelved in favor of continuing a policy of drift and indecision which has characterized the program from the very start. This action has been taken in spite of general agreement in both the Defense Department and AEC that a direct cycle propulsion system, utilizing available materials, is now in existence for use in an initial test flight aircraft of limited performance.

As I stated in the past, I have had the feeling all along that there has been considerable confusion over this question of so-called usefulness. I think it is high time that we nail down once and for all what is meant by usefulness, and then get on with the job. From my own point of view, and that of the working engineers in the field, the most useful thing we can do at this point is to test out the propulsion system in actual flight as soon as possible. No one has ever pretended that this first flight would involve a fully operational military aircraft. Far from it, the first flight in line with historical precedent would be a distinctly limited affair, aimed specifically at providing information which is vital to the subsequent development of a fully operational aircraft.

It is my understanding that we are in fact technically ready to proceed with this limited first flight and further delay will only put off the time when we reach a fully operational capability.

After the many years we have discussed this matter in closed session, at the request of the executive branch, I believe the time has come for a public airing of this matter so that the American people can be better informed of the true facts of the situation. I believe that these hearings can be held in public session without endangering the national security. On the contrary, I am convinced that the national security will be enchanced by a well-informed public opinion.

This morning we will be receiving testimony from the project director, General Keirn, and representatives of the Air Force and Navy. This afternoon we will hear from Chairman McCone of the AEC, Mr. Gates, the Deputy Secretary of Defense, and Dr. York, Director of Research and Engineering, at the Department of Defense.

General Keirn, I believe you are prepared to lead off this morning with a description of the program's present status and the recommendations which you as the project director have made regarding the course we should follow in the future.

Before you start, General, I would like to pay a sincere compliment to you, Colonel Armstrong, and the other able members of your staff for the steadfast way you have persevered in your job, sometimes against great obstacles, and in the most trying circumstances. Your countrymen owe you a deep debt of gratitude for the lifetime of effort you have devoted to the Nation's security, and I think it is entirely proper that we record it here at this point.

Would you proceed with your prepared statement, General?

Chairman Anderson. Before he starts, after that nice comment, I would like to put in a bad note. General, we have been trying to make sure that the departments comply with the Legislative Reorganization

Act, and have testimony 24 hours in advance. I suppose you know that we had to keep our office open until 11:30 last night to get a copy of your statement. Did you hold it up or did the Department of Defense hold it up?

STATEMENT OF MAJ. GEN. DONALD KEIRN, DIRECTOR, AIRCRAFT NUCLEAR PROPULSION PROJECT

General KEIRN. It could be that I did not submit it early enough for them to have reviewed it.

Chairman ANDERSON. Is 3 or 4 days not enough?

General KEIRN. I started its submission for review on Monday. It did run into problems since that time, and whether it would have gotten through faster if I had submitted it last week I don't know. My office stayed open last night, too, trying to get it out.

Chairman ANDERSON. Was it pretty substantially rewritten by the Department for you?

General KEIRN. No; it turned out that it was not substantially rewritten. There were some modifications in phraseology, all of which I was very happy to accept.

Chairman ANDERSON. General, I don't differ at all from what Mr. Price said in his tribute to you. We appreciate the fine work you have done. We wrote to the Department of Defense and to the Atomic Energy Commission hoping that this testimony might be in 24 hours in advance. I am sorry it was not.

General KEIRN. I regret that it was not.

Representative HOSMER. Mr. Chairman, I would like to join in the tribute to General Keirn as well. However, in connection with some of the other portions of your statement, I would want to make my position clear that I am not fully in accord with all of them.

Representative PRICE. That is natural. No one, particularly on a congressional committee, could be in full accord with all of them.

General Keirn, would you proceed with your statement?

General KEIRN. Yes, sir. Mr. Price, members of the Joint Committee, before I begin with my prepared statement, I would like to say a word or two about my position as Chief of the aircraft nuclear propulsion program. I have responsibility both to the Atomic Energy Commission and to the United States Air Force. I have prepared a statement which reflects my personal views of the ANP program.

I may cover things in my statement which are not within the purview of the Atomic Energy Commission, and I may cover things in the statement which are not within the purview of the Air Force, and I may say things that represent my personal view which does not necessarily represent the concerted view of either of the services. So I would like to make this point clear before I begin my prepared statement.

This is the first hearing that has been held on the aircraft nuclear propulsion program in open session. We welcome the opportunity to bring additional information on the program to the public. We have, in the past year, presented carefully prepared unclassified papers before a number of scientific forums. I hope that this open hearing will help to clarify some of the apparent misunderstandings with regard to the manned aircraft portion of the ANP program. I say

manned aircraft portion of the ANP program because, as the committee knows, the ANP also includes projects to develop rocket and ramjet propulsion systems, initially for unmanned vehicles, and nuclear auxiliary power sources. Since this hearing has primarily to do with the manned aircraft program my use of the term "ANP" in this statement shall apply primarily to the manned aircraft program.

Representative PRICE. That is correct, General. We are concerned here now with the manned portion of the program, the nuclear-powered aircraft referring to the manned aircraft.

General KEIRN. I am sure that it is realized that the ANP program is the major program in this country which places prime emphasis on the development of very high temperature, high power density nuclear reactors. The technology gained in the ANP program will benefit the country's technological position in many areas. For this reason there is a very strong urge to declassify the ANP program in order to make the technology available to other associated military and civilian programs.

We have recently reviewed our classification guide under ground rules which should enable us to declassify some segments of the program. This I hope will serve two purposes. First, it will permit a more general application of some of the technology developed in aircraft nuclear propulsion towards some of our other reactor programs; and, second, and quite important to me, it will permit certain simplifications in management procedures, and thus permit economies within the ANP program itself. However, I am sure this committee would agree with me that certain advanced work which may enable this country to produce superior nuclear aircraft should not be compromised by declassification. Thus, classification must be continually scrutinized. We are not proposing to relax our security vigilance on some of the more advanced technology in the ANP program, and we have been so guided in the preparation of our report to this committee today.

This committee is well informed on the history of the ANP program. Inasmuch as the committee wishes to hear the testimony from a number of witnesses today, I will restrict my remarks to certain pertinent points having to do with objectives of the manned ANP program and to the discussion of certain issues which are before us. With the committee's permission I will submit for the record, at a later date, a more complete discussion, within the bounds of security, of course, of the technical status of the manned aircraft portion of the aircraft nuclear propulsion program. Such a report should be available within a day or two. (See p. 28.)

Representative PRICE. The committee would appreciate the submission of such a report.

General KEIRN. The first point I wish to make is that a basic requirement in the accomplishment of the Air Force's primary strategic deterrent mission has been the development of the capability to deliver devastating striking power to the heartland of any enemy nation wherever that nation may be geographically. This requirement has imposed upon the Air Force the necessity to develop long-range bombardment and reconnaissance aircraft. The range limitations of chemically fueled aircraft have forced us into dependence upon aerial refueling and staging techniques, the latter requiring the procurement

and support of air bases on foreign land. Nuclear-powered aircraft will eliminate these operational complexities and lessen our reliance on the availability of foreign bases. The advantages of the additional operational flexibility, greater mobility, reduced operational complexity, and extended range and endurance available to the combat commander cannot, in my opinion, be overstressed. It is to satisfy these operational requirements that the Air Force, in cooperation first with the Manhattan project and later with the Atomic Energy Commission, has been supporting the development of nuclear powerplants for aircraft propulsion.

Another point I wish to make has to do with other mission applications. We have evaluated Air Force requirements in other mission areas such as logistic transport and airborne early warning. We have not yet been able to find an economical basis for establishing operational requirements for nuclear-powered aircraft to accomplish these missions. The cost involved in this program has appeared warranted only by the priority of the Air Force's primary strategic deterrent responsibilities. The program has not, therefore, been initially oriented toward powerplants characteristic of the other mission requirements. One should keep in mind, however, that the technology currently being developed for strategic systems will be directly applicable to other objectives when detailed requirements for such objectives are established.

Turning now to those mission areas which appear economically justifiable, in 1955, general operational requirements No. 81 was promulgated by the Air Force. This requirement called for a nuclear-powered strategic system in which the vehicle would cruise at subsonic speeds on nuclear power alone, but would be capable of a high-altitude supersonic dash by augmenting the nuclear thrust with chemical fuel. A program to meet this requirement was initiated in weapon systems 125–A. When detailed design of reactors meeting these requirements were underway, certain limitations in the physical properties of available materials were encountered which resulted in an unacceptable reduction in predicated system performance. To be more specific, the predicted dash radius became less than desired and predicted aircraft weights became greater than desired. These limitations indicated the need for further basic materials development (structural, fuel element, and moderator materials) before reactors meeting the criteria of general operational requirement No. 81 could be produced. It appeared, therefore, ill advised to continue a full weapon system development program to meet this requirement until further advances in the reactor art could be achieved.

I would like to ad lib that this indicates a need for carrying out engineering development work along with the basic reactor work because it was through detailed design that we were able to determine that we were not in the position to enter into a development program on this weapons system.

During the last year or two, a number of additional factors which have an important bearing on the Air Force's strategic capabilities have been claiming the attention of our operational analysts. One of these is the complexity and cost of dispersion of our strategic forces and hardening our missile bases. Another solution which is under serious consideration today is the continuously airborne strike

force. To maintain a reasonable percentage of our manned chemical bomber force airborne and capable of immediate strike action is a most costly endeavor, primarily because of the refueling tanker force required. Nuclear-powered aircraft would permit us to maintain a continuously mobile force which would be relatively invulnerable to surprise attack, and which would allow us to instantaneously react to international developments through our ability to rapidly deploy the mobile force anywhere in the world and at the same time continuously maintain direct command control over such force. A high subsonic speed nuclear-powered aircraft possessing long flight endurance, large payload capacity, and the ability to launch stand-off missiles and penetrate the enemy heartland at minimum altitude can be achieved within the state of the art and on a predictable time basis. General operational requirement No. 172 for such a weapon system was issued by the Air Force in October 1958, and this weapon system has come to be known as the CAMAL (continuously airborne, missile launching and low level penetration) system. The program on which we are placing primary emphasis today is one directed toward the development of a propulsion system for such an airplane. We have proposed the initiation of the development of two experimental aircraft to serve the dual purpose of flight testing this propulsion system and of serving as prototypes of an aircraft which would meet the vehicle role in this general operational requirement.

I would like to digress a moment to discuss the procedures for establishing requirements since this is a pertinent topic under consideration at this hearing. During the last 6 months, there has been a change in the Air Force procedure for establishing requirements. General operational requirements are in the process of being replaced by specific operational requirements and system development requirements. Specific operational requirements are documents which describe in specific terms the characteristics of a weapon system required to meet a near-term operational requirement, the satisfaction of which is compatible with the technical state of the art, and for which a production program is considered desirable. System development requirements are documents which describe in general terms the characteristics of a new system required for the attainment of a forecast operational capability requirement presently beyond the technical state of the art, and for the exploitation of a significant technological advancement in a projected military application. The system development requirement is broad in approach to permit the flexibility and latitude required in development, yet specific in purpose to guide and orient the development toward a definite goal. I believe general operational requirement No. 172 should now be considered in terms of a system development requirement. In this context, it is also my opinion that the intent of the Joint Chiefs of Staff statement, which will be discussed later, is to support a system development requirement for a nuclear-powered airplane but not a specific operational requirement.

There has been a great deal of discussion in the press as well as in official circles with regard to the importance of flight-testing nuclear propulsion systems as an essential development step, and a great deal of discussion as to whether the flight test vehicle could be a modified version of an aircraft already in production and service or whether

this aircraft should be a new aircraft designed specifically for the purpose. I have testified before this committee on two prior occasions that if there were no plan to build an aircraft which might serve as a prototype of an aircraft meeting some military requirement, that it would be necessary, in the propulsion system development process, to put an experimental nuclear powerplant in some sort of airframe for flight-testing purposes.

I also testified, however, that should a weapon system be contemplated, the prototype for such a weapon system designed specifically for nuclear propulsion would be by far the preferable aircraft for initial flight-testing of the nuclear propulsion system. These two alternatives have received extensive study. The results lead to our present conclusion that an airplane built specifically for nuclear propulsion provides the better means for nuclear powerplant testing.

Last fall, the Air Force conducted a design/management competition for an aircraft meeting the CAMAL design criteria. This competition has been completed, the results evaluated, and the Convair Division of General Dynamics declared the winner.

While the airplane configuration for the flight-test vehicle has not been finally established, the Convair model 54 airplane proposed by Convair in this design/management competition offers many attractive characteristics for a nuclear powerplant flight-test vehicle because of its flexibility with regard to payload and the greater latitude with regard to nuclear powerplant testing which it provides as compared to a modified aircraft. While a decision has not been made to initiate development of this particular design, and further considerations will be given to variations in aircraft configuration to provide the most flexibility for nuclear propulsion system testing, it does appear that an aircraft which will provide a maximum of operational flexibility and safety for nuclear flight-testing will have many of the characteristics of an airplane which would satisfy or permit us to test completely the CAMAL mission concept. It is important, therefore, to proceed with the development of the two new aircraft having the general characteristics of the Convair proposed model 54 in order to initiate a flight-test program on the propulsion system presently under development and on subsequently improved systems. Further decisions with regard to complete weapon system development should follow only when we have achieved enough progress in the two airplane programs to assure the soundness of such decision.

While our primary effort has been centered on a direct cycle reactor propulsion system to meet the CAMAL operational requirements, we are, at the same time, carrying along a vigorous research and experimental effort to develop an indirect cycle reactor for aircraft powerplant use. Preliminary design studies of indirect cycle powerplants have revealed the possibility of thrust to weight ratios which would make possible manned systems possessing high altitude and supersonic speed performance on nuclear power only. We cannot schedule this on a definitive time scale since extensive research and materials development are involved, but recent progress in this area is most promising and a nuclear propulsion system for a B–70 type aircraft appears possible.

And now I wish to say a word about Navy participation in the program. The Navy has participated on a minor scale since the

inception of the ANP program. The Air Force and the Atomic Energy Commission have continually shared the technology developed in the ANP program with the Navy and have offered to satisfy Navy requirements in the ANP development effort. In 1955, the Navy expressed an increased interest in the ANP program, and it was agreed that the Navy would furnish some personnel to my staff in the Aircraft Reactors Branch in the Atomic Energy Commission in order to assist the Navy in keeping abreast of progress in the program. It was the understanding between Admiral Russell, then Chief of the Bureau of Aeronautics, and myself, that the Navy participation was not to generate into a competition to fly first, but that the Navy's interest was to follow progress and apply such reactors that might be developed to Navy use at such time as might be appropriate. Their attention at present is directed toward nuclear turboprop propulsion for a flying boat. They have examined both the direct and indirect cycle systems for this purpose. It appears that under the present state of technology the indirect cycle will permit meeting their shielding requirements at lower overall propulsion system weight than would the direct cycle. Consequently, at Navy request and with the approval of the Department of Defense, the Air Force and the Atomic Energy Commission are making arrangements for active Navy participation in the indirect cycle development effort at the Pratt & Whitney operated CANEL facilities (Connecticut Aircraft Nuclear Engineering Laboratory).

I have covered briefly the objectives of the manned aircraft nuclear propulsion programs, and the proposal by the Aircraft Nuclear Propulsion Office to proceed with a flight test program.

Let me say these basic issues are primarily a matter of technical judgment. One issue of long standing is the usefulness of nuclear-propelled aircraft in the strategic role in the time period when ballistic missiles will be available in sufficient supply in our arsenal. A full discussion of this issue is, I think, beyond the intent of this hearing. The answer, of course, involves human judgment because there is insufficient experience upon which to base a categorical determination. I would simply like to say for the purpose of this hearing that the Chief of Staff of the Air Force has stated, on numerous occasions, and I believe he may state in his testimony later today, that manned aircraft will be required within our total complex of weapon systems in the foreseeable future.

Another issue is the definition of what constitutes a militarily useful aircraft or a militarily useful powerplant. It would appear that an airplane which could serve initially as a flight test vehicle, and subsequently the experimental vehicle component of a possible weapon system might be termed a useful military vehicle. With regard to a militarily useful powerplant, a negative argument has been advanced that military utility can be achieved only when turbine inlet air deriving its heat from the nuclear heat source equals or exceeds the turbine inlet air temperature contemplated for advanced chemical turbojet propulsion systems. This, in my opinion, is a fallacious line of reasoning. The turbine inlet air temperature for chemical turbojet engines is determined primarily by powerplant weight, frontal area, and specific fuel consumption considerations under the design operating conditions. In the subsonic flight regime,

high turbine inlet temperatures result in lower propulsive efficiencies. Consequently, an optimized propulsion system taking into account weight, frontal area, and specific fuel consumption has not required intensive efforts to increase turbine inlet temperatures.

In the supersonic speed range, this situation may be reversed, and it will be desirable to go to higher turbine inlet temperatures. Much higher turbine inlet temperatures can and will be achieved through materials research and through turbine wheel and blade cooling. Turbines can without a doubt be designed to utilize air at any temperature that can be generated by a heat transfer type nuclear reactor. Thus, it is impractical, if not impossible, to establish a meaningful criteria for nuclear propulsion systems on the basis of turbine inlet temperatures alone.

Still another issue and the one most pressing at the present time involves the appropriateness and the timing of initiating the flight test phase of the development of nuclear aircraft propulsion systems. It is my personal conviction that we have reached a point where it is now appropriate to commence the design and construction of an experimental aircraft suitable for flight testing the propulsion systems presently under development and of evaluating the operational characteristics of such an aircraft as a first step in determining the manner in which the unique capabilities of nuclear power in the air can best be utilized. Commencing such flight testing with a propulsion system, even though it does not meet the military performance as specified in general operational requirement No. 172, still serves the purpose of developing the powerplant external to the reactor core, the powerplant-airplane combination as a complete machine, and permits us to tackle the many problems of flight, maintenance, servicing, and problems associated with operational techniques irrespective of whether or not the aircraft would be flown at maximum performance. I believe that these problems can be solved concomitantly with the development of improved reactor cores and that these improved cores can subsequently be installed to provide full performance of the aircraft. Waiting for the full performance cores before initiating such a flight test program needlessly delays the program, and in the long run is a more costly procedure. We can tackle many problems with the reduced temperature reactor core which we now know how to build and have many of those problems associated with the flight test phase solved by the time we are ready to install a core which will operate at a temperature necessary to provide military power.

There are other engineering judgments with regard to the use of a split shield versus a unit shield. There is a role for unit shielded powerplant in aircraft designed for certain missions, but I wish to point out that there will always be a weight advantage in the split-shield concept and that for military missions such as the strategic mission it will be to our advantage to use the split-shield concept to keep the propulsion weight as low as possible in order to maximize payload, altitude, or speed capabilities. The work that has been done and is contemplated in the field of radiation effects is in my opinion entirely justified if we are to fully exploit the use of nuclear power for military aircraft.

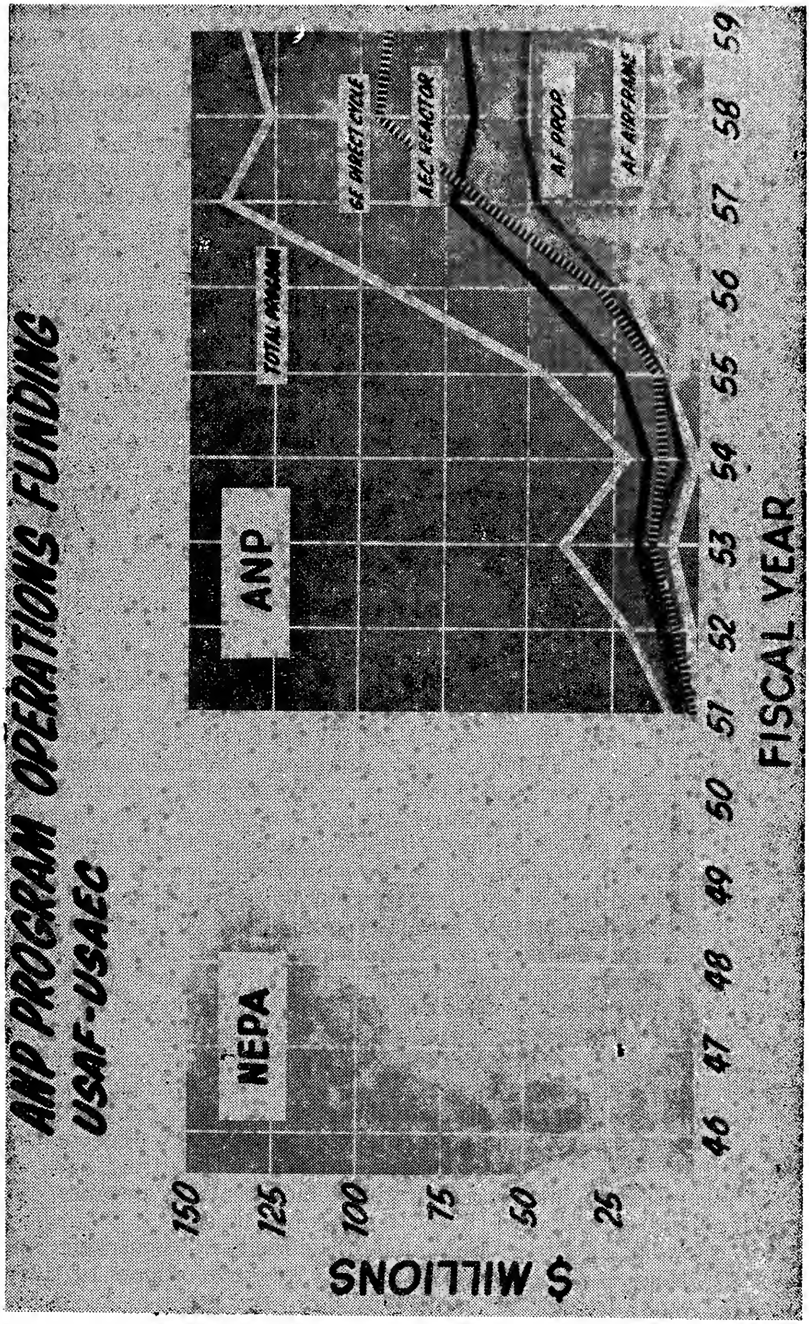
The latter remark, of course, refers to the fact that in the split-shield concept we must continue this kind of investigation in order to provide radiation resistant materials for the airplane.

Let me return now to the broad objective of the ANP program. As I indicated in my opening remarks, the objective of the ANP program has been to develop a strategic weapon system which would eliminate the range and endurance limitations of chemical aircraft systems. This was the Air Force objective in 1946 when the exploratory program on nuclear propulsion known as NEPA (nuclear energy for the propulsion of aircraft) was inaugurated. It has been the primary objective of the manned aircraft nuclear propulsion program ever since, and it is the objective today. Only the details of the technical program to achieve these objectives have changed. Some steps have been eliminated for economy reasons, other steps have been modified for technical reasons. Those changes brought about by technical reasons have had sound, valid bases as I will indicate.

Let us examine for a moment the direct-cycle program. The General Electric Co. chose the direct cycle as the most practical route for the initial development of a nuclear propulsion system for aircraft. This choice was made in September 1951. It was made by a team of General Electric technical people after extensive review of the work done by NEPA and appraisals made by the Lexington group and the technical advisory board. This approach has not changed. In technical detail, the first reactor proposed by the General Electric Co. would have been water moderated, and it was proposed at that time that such a reactor be flight tested in two modified B–36 airplanes—the X–6's. It was recognized at that time that the water-moderated reactor—R–1—would not provide a suitable tactical powerplant, but the flight testing of this powerplant in a B–36 airplane would permit attack on many of the problems of nuclear-powered flight, and provide the understanding through which advanced tactical powerplants could be produced. This flight test element of the program was rejected by the Department of Defense on the basis it would not provide directly for a militarily useful powerplant, and consequently did not warrant the dollar expenditure.

I would like that you note that at this same period a high temperature moderator reactor—the AC–1—was on the drawing board at the General Electric Co. From this reactor concept has sprung the XMA system, which efforts have constituted straight line development toward a tactical powerplant. You will note there has been a fluctuation in flight-testing philosophy, brought about by decision at the Department of Defense level, but there has been no change in the technical direction of approach of the propulsion system. Subsequent to the X–6 decision, the Department of Defense announced that the objective of the ANP program was a propulsion system suitable for a useful military aircraft. There has been no change in this policy, and the ANPO has adhered to and followed this policy.

I have prepared one chart. I am assuming that the top line represents total expenditures.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You will note from this chart of expenditures a continuous and smooth growth on the part of the direct-cycle program—and I believe that is the dotted line—in spite of the fluctuation in planning money which resulted from the planned and abandoned 125A system. As I indicated earlier in my statement, the abandonment, or perhaps I should say postponement, of the 125–A system was brought about by technical reasons, and is indicative of recognition of technical problems and subsequent appropriate program modifications.

The objective to develop a militarily useful direct-cycle propulsion system of the XMA type has remained unchanged, and still forms the basis for our major line of endeavor.

Let us turn now to the indirect-cycle program. The Pratt & Whitney Co. was brought into the ANP program to examine the feasibility of a supercritical water reactor propulsion system, and to compare such a system with the circulating fuel reactor propulsion system under study at the Oak Ridge National Laboratory. This study and comparison was made. The Pratt & Whitney Co. recommended that it also examine the solid fuel element, liquid metal cooled reactor concept, and it was authorized to do so. The supercritical water cycle system was discontinued on the basis of lack of growth potential. A detailed engineering design effort was initiated on the circulating fuel reactor system, and structural materials limitations indicated the inability to produce such a system in a power range suitable for 125–A mission requirements. The circulating fuel reactor system was, therefore, dropped for technical reasons. While this system might have been feasible to meet CAMAL requirements, it appeared unwise from a dollar standpoint to undertake two propulsion systems to meet these requirements. Work on the solid fuel element liquid metal concept has continued and now shows promise for high performance future propulsion systems as well as for lower power systems where unit shielding is an important consideration. Work on this system is, therefore, proceeding as rapidly as is technically prudent. In my judgment, therefore, the changes which have taken place in the indirect cycle program has followed the line of prudent evaluation, and appropriate elimination of less promising directions of approach.

I would like to point out that continuous improvement in reactor materials has been achieved in the course of the ANP program and this has made it possible to continually predict improved reactor performance. This does not mean that we initially chose to work on low performance material to meet early flight dates, but rather that our intensive effort on reactor materials has been fruitful. Reactor materials which now appear promising were under study during the early days of the ANP program. It has been the research and development effort on these materials that now makes them appear promising. That we did not initially begin at the top is because we did not know enough to begin at the top. Incidentally, the ANPO, itself, has turned down proposals to meet early flight demonstrations because of the lack of growth potential of the systems proposed.

Now one word about facilities: All of the facilities constructed under the ANP program have been required for the development of the propulsion system, except in the case of these facilities supplied to the aircraft contractors for the purpose of studying shielding problems and radiation effects problems. These facilities represent a relatively

small percentage of the ANP facility complex. I believe about 12 percent. The FET facility in Idaho is basically a flight engine propulsion test stand. It was so designed that it could be used in connection with a flight program. However, it is not a flight facility, and would have possessed a very similar design characteristics whether or not a flight test program has been contemplated at Arco.

In summary, let me say for the integrated Aircraft Nuclear Propulsion Office, that it is now our business as project managers to orient the program in such a manner as to achieve a propulsion system that will provide the specific thrust and gross thrust that meets Department of Defense criteria for military utility. It is my view, furthermore, that it is the responsibility of project management to determine the technical program, and the steps necessary in achieving the specified objectives always with due respect to technical advice from within or without the program in making these decisions.

That completes my statement, Mr. Price.

Representative PRICE. Thank you, General Keirn. This is a comprehensive report. I would like to start the questioning by the committee by referring to the statement which you made on page 5, about the middle of the page, where you said:

> A high subsonic speed nuclear-powered aircraft possessing long flight endurance, a large payload capacity, and the ability to launch standoff missiles and penetrate the enemy heartland at minimum altitude can be achieved within the state of the art and on a predictable time basis.

Does that mean we have sufficient technology at the present time if we should set a time basis to put the first plane in the air within a reasonable time period?

General KEIRN. That is the intent of my statement, Mr. Price. I must clarify it. That does not mean that research and development is done and that we could withdraw our research and development people and put it into production. I did not have this in mind. I have in mind, though, that the rate of progress and the unknowns are of a nature which we can predict their solution on a time basis.

Representative PRICE. I would not interpret the statement to mean that you had completed the technology to immediately go out and put a plane in the air. I did interpret it to mean that the technical knowledge which we now have, within a reasonable time, with what we know now and with the material that we have now, we could put a first plane in the air.

General KEIRN. With materials which we have now and the subsequent development of certain techniques involving them, yes.

Representative PRICE. Which we anticipate on the basis of progress that we have already made, the experiences that we have had in the program, and with the success that we have already attained in meeting certain time schedules.

General KEIRN. This was my intent, sir.

Representative HOSMER. Would the gentleman yield on that particular point?

Representative PRICE. I yield for a question.

Representative HOSMER. On the following page of your discussion of system operation requirements and system development requirements, you again mention this aircraft, but in the context of a system development requirement which contemplates something beyond the

technical state of the art at present. In other words, I am disturbed as to a conflict between those two statements. Can you clarify that?

General KEIRN. Yes, I can clarify it. I believe the Air Force position is this. We do not know yet that the CAMAL weapon system is a system which we want to put in production. My statement to the effect that we could have an airplane which would meet the characteristics required of the CAMAL system on a timely basis does not mean that the Air Force intends to put that airplane into production to produce a CAMAL system. This is the point I wish to make in saying that they have now divided the requirements into specific operational requirements and a more generalized development plan.

Representative HOSMER. Does that mean that General Operational Requirement 172 is out now?

General KEIRN. It is not out yet, because we are in the process of setting up these two kinds of requirements, and when these are set up, GOR 172 probably will be rewritten. When there is a rewrite of it—I don't know when that will happen—GOR 172 may be out and another requirement of a different title is published. I don't know how that will be handled.

Representative HOSMER. If it goes from GOR to SDR, it goes on a more remote basis, does it not?

General KEIRN. You will note from my definition of these two requirements that there is a specific intent to go into production in the case of one. In the case of the other, no decision has yet been made. In the case of CAMAL, no decision has been made to go into production. It has been our recommendation, however, that we build experimental aircraft to investigate the characteristics of such an airplane.

Representative HOSMER. I want to ask you further along that line, but I believe it is appropriate to do so later.

Representative PRICE. What target date, if any, exists in the program as it is now constituted for a ground test prototype or a flight test?

General KEIRN. There is no specific date for initiation of a flight test program at the present time, Mr. Price.

Representative PRICE. I also inquired about the ground test prototype.

General KEIRN. I think the committee knows essentially this date. There may be some slippage in it.

Representative PRICE. Without mentioning the date, do you regard it as a firm date now?

General KEIRN. No. I would say I don't because I am now looking at it.

Representative PRICE. Then you might say that actually there are no target dates.

General KEIRN. I think that is probably right.

Representative PRICE. Would an early flight program detract from the achievement of a high performance military aircraft later on, in your opinion?

General KEIRN. One has to put certain boundaries on a question of this kind, Mr. Price. Funding has a lot to do with it. I think that if one put everything he had into just building an airplane and building a specific propulsion system for that airplane, research and development on an advanced system would have to suffer from it.

Representative PRICE. I am thinking about whether or not an early flight would assist.

General KEIRN. It would contribute immeasurably in getting along with the job of producing useful nuclear-powered aircraft if we do not get hemmed in from a dollar standpoint.

Representative PRICE. You talked in one place in your statement about the servicing of the plane after we have one in flight. You mentioned the various things that we would learn just from handling a plane on the ground. What period of time would be involved to learn these things?

General KEIRN. It is rather hard to say. Usually a new airplane undergoes a period of about 18 months flight testing to just get the bugs out of it, and learn what the airplane is and its handling. I am not sure that one ever reaches the point in such a flight test program where he can say I know all the answers now about how we operate nuclear airplanes, but I am sure we would reach a point where we could say I know enough about these problems and I would say in a 2-year flight test period we could say we know enough about these problems to know just how useful nuclear power is to us.

Representative PRICE. You could almost save a period of 18 months to 2 years just from what you have learned from servicing a plane that has actually been in flight and handling it on the ground, particularly on the nuclear-powered aircraft.

General KEIRN. I think it is very important.

Representative PRICE. That you would have this knowledge before you put the second generation in the air.

General KEIRN. Yes, sir.

Representative PRICE. You said you will note that there has been a fluctuation in flight testing philosophy brought about by decision at the Department of Defense level, but there has been no change in the technical approach of the propulsion system. Would you elaborate on that statement? What do you mean by that?

General KEIRN. I meant that when we proposed a flight test program in the X–6 airplane, that is the modified B–36, this was purely a flight test vehicle. It had no other function than to merely carry the nuclear propulsion system up in the air and give us an opportunity to make the measurements on that nuclear propulsion system under the conditions of flight. This program was, as you know, abandoned. Since then we have directed our attention toward producing a useful military airplane and our attention primarily has been focused on using that military airplane as a flight test vehicle. There has been a great deal of consideration about going back to the test bed concept. I think I have covered in my opening statement the fact that if we are not to proceed with an airplane that has useful characteristics, I think in the development of the propulsion system, just to be sure that it responds properly in the air, one must sometime flight test. I say this primarily because we don't have a wind tunnel facility to put it in. If we had a Tullahoma wind tunnel facility to put the powerplant in, we might be able to dispense with it, and say we have a nuclear powerplant suitable to propel an airplane, without ever having flown it. Without having the kind of wind tunnel facility, I don't think we can ever say we have a nuclear powerplant for aircraft propulsion without having put it in the airplane and flown it.

Representative DURHAM. Is there a wind tunnel in existence which can provide that information?

General KEIRN. No. It is the radiation problem that has us stopped there primarily.

Representative DURHAM. We have built them as large as requested.

General KEIRN. They are not built with shielding around them and things of that sort.

Representative DURHAM. Couldn't that be done very easily?

General KEIRN. It would be very expensive.

Representative DURHAM. They were expensive to begin with.

General KEIRN. This would add materially to the cost. I am sure it would far exceed the cost of getting a flight test program.

Representative DURHAM. I feel pretty keenly about the wind tunnels, General, because of the fact that we have provided the necessary wind tunnels on request here in the Congress, and all they have asked for, as far as I know. I handled most of them before they went to test flight. They laid down the requirements. They knew that radiation was going to be one of our problems, so why has not somebody provided for it?

General KEIRN. When Tullahoma was designed, we were neophytes in this nuclear airplane propulsion business.

Representative DURHAM. That is true. We began first talking about this in 1946, and we did not have any wind tunnels until after 1945 in this country.

General KEIRN. That is true. As I recall, Tullahoma was being designed and worked on about the same time that we started the ANP program.

Representative DURHAM. How about Langley?

General KEIRN. Langley had been in existence for some time. Their tunnels were all very small. If we are going to test a full-size nuclear reactor, and it will be with the split shield concept initially, there is a reasonable field of radiation around the reactor.

Representative DURHAM. That is true.

General KEIRN. There is a reasonable nuclear hazard associated with the initial test, also. This is the reason why our reactor test station, as you know, is in a remote site out in Nevada.

Representative DURHAM. I feel that you have been given all the responsibility here and not given much authority. Have you made any recommendations to the Defense Department that this thing is a requirement?

General KEIRN. Yes, sir, I have made recommendations that we must get on with a flight test program.

Representative DURHAM. I don't mean that. I mean on this testing business. You seem to think that is one of the things that you have to know before you go any further.

General KEIRN. I have made this very clear, I think, Mr. Durham, and I think it is recognized that sometime this reactor has to be flight tested. I don't believe the fact that sometime it has to be so tested is really an issue. I think the issue is when do we do it.

Representative DURHAM. Have you made the request of the Defense Department that this is one of the necessary requirements in developing a nuclear-powered airplane engine because of the radiation hazard? That you have to have this testing facility?

General KEIRN. I have not made a request for a wind tunnel test facility, Mr. Durham. I have not requested this.

Representative DURHAM. If it is necessary, I think somebody should.

General KEIRN. I don't think it is necessary, Mr. Durham, provided we can proceed with a flight test program.

Representative DURHAM. I believe that is true. Wouldn't it be safer in the long run? They laid down here an operational requirement, as I understand. That is what you are faced with. They have not deviated from that. I always have supported the early test flight. I still feel it is sound. I think you are going to have to do it in the end before you get anywhere with this job. I may be wrong, because I am not a scientist.

General KEIRN. I am sure you are right.

Representative PRICE. General Keirn, do you believe that materials presently available for the direct cycle propulsion system are adequate to proceed with a limited nuclear flight program for experimental purposes?

General KEIRN. Yes, sir.

Representative PRICE. Do you believe that an early flight program would be possible in the early 1960's if additional funds were provided?

General KEIRN. I believe it would be, sir.

Representative PRICE. How much additional money would this be over and above the present level of support?

General KEIRN. I think the committee has been given these figures. Maybe I have it here. I think it constitutes about $320 million spread out over a period of 5 years, not uniformly.

Representative PRICE. I think the period was 4 years. I think the monetary figure sounds correct.

General KEIRN. It depends upon how rapidly you move and in what years you want the peak to occur. We have already lost a year. I think we are thinking now in terms of 4½ to 5 years. Of course, that includes some flight testing.

Representative PRICE. Do you believe that the overall cost of producing a militarily useful airplane will in the long run be more or less expensive if we proceed with a flight program now?

General KEIRN. It is my opinion that you have a basic cost of the R. & D. program that runs continuously. When you reach the stage where you can technically move into a flight test program, it is time to do it, because if you postpone it, your basic costs are continuing to run but the costs of moving into the flight test program essentially are unchanged. So I think year by year the program becomes $150 million more expensive.

Representative PRICE. It would be more expensive by delaying a decision to step up activity to the point where we could have a flight within a period of 3 or 4 years.

General KEIRN. I think this is so, Mr. Price, on the basis that it is the kind of airplane and the kind of test program we are presently proposing. If it is some airplane that is more advanced or that we don't know about, then this would be a different story.

Representative PRICE. Subsequent to the most recent decisions in connection with the program, what, if anything, had been done on

eliminating work on available reactor material for an early flight plane in favor of more advanced materials? Has there been a noticeable change?

General KEIRN. Let me be sure now that I understand your question. You say have we done anything at present to change the amount of work on existing materials to move into the advanced area.

Representative PRICE. Yes.

General KEIRN. We have not at the present time taken any move in this direction. We will in all probability do so in the very near future.

Representative PRICE. How much will this delay the overall plan for a flight program?

General KEIRN. I would hope not to destroy the base from which we could move into a flight test program when such flight test program is approved. I think we were still saying that the flight test program will be delayed by whatever length of time it takes for a decision to be made to move into it.

Representative DURHAM. General Keirn, you just made a statement a few minutes ago which I think is rather interesting and important, that is, going ahead and not going ahead with respect to the cost. Eventually won't we spend a good deal more money on that basis?

General KEIRN. I am of this opinion, Mr. Durham.

Representative DURHAM. It will cost less?

General KEIRN. No, that it is going to cost us more as we proceed.

Representative DURHAM. On this basis of not making a decision.

General KEIRN. Yes.

Representative PRICE. General Keirn, this program has been plagued all along by a lack of target dates, but there has been a certain amount of scheduling, particularly at the technical level and at the working level on different phases of the program. What has been your experience with the contractor meeting the schedules that they have set up in the course of the program?

General KEIRN. My experience has been that when a specific element of the program has been approved and has been in the financial plan so that they have had the money to carry it out, they have in general carried it out on schedule. I mean there may have been small slippages, but in general they have met the milestones that have been approved and funded.

Representative PRICE. I would now like to ask you your personal opinion on these types of observations in opposition to a nuclear powered airplane. One is the enormous weight of the airplane. Another is that the shielding problems are insurmountable obstacles. Then the other is the danger of flying a reactor over the heads of millions of people. In your opinion, do you feel that the problems of shielding and weight of the aircraft pose an insuperable obstacle to nuclear flight?

General KEIRN. Addressing myself first to the question about shielding weights, I do not regard them as representing an insuperable problem. The shielding weights, while I won't be specific, don't represent the total weight of chemical fuel that is carried aloft by one of our big bombers whenever it goes on a mission. I don't regard substituting a shield which weighs less than the fuel which you normally carry for that fuel as representing an insuperable load.

Representative PRICE. As a result of the amount of work that has been done on the problems of shielding, and so forth, you are pretty much in the area now where you feel and people in the program feel that this is no longer an insuperable obstacle?

General KEIRN. Most certainly it is not an insuperable obstacle. I want to say that we have bit by bit improved our technology in shield design so that our confidence in our weight estimates are within perhaps a factor of 10 percent or less. So this does not represent a problem in going into an initial flight test program.

I wish to point out, though, that it is my personal conviction that when we do move into a flight test program we will find ways in which we can tailor the shield and maybe reduce some weights that we will never find until we move into the flight test program.

Representative PRICE. This is one of the advantages of early flight.

General KEIRN. Yes, sir.

Representative PRICE. It is one of the things you are not going to develop more rapidly possibly than you have to this point from the experiments you have already made until you do put a plane in the air?

General KEIRN. I think that is correct.

Representative PRICE. What danger exists from fission products released in the direct cycle system using reactor material presently available?

General KEIRN. The presently available materials in general don't release fission products unless you have had some kind of a failure. There are some prospective materials which show a great deal of promise and which might release fission products in amounts that might bother us on a test stand where the powerplant is in a fixed location. We have not done as much study on this as we need to do, so I am not really prepared to say how serious a matter it would be in flight.

Representative PRICE. Do you get less fission products from the materials that we have done considerable work on up to date, or on the advanced materials?

General KEIRN. I would say it is an advanced material which I refer to as being a very useful one, but having a disadvantage of perhaps putting out fission products.

Representative PRICE. Does this pose a serious problem in flight? We can see it would be a little bit different in the exhaust from a plane on takeoff. There has been considerable work done on that. But does it also pose a problem in flight?

General KEIRN. We have not performed sufficient analyses on this matter for me to feel comfortable about giving you a positive answer on that. If this were the case, one would consider it in connection with such other specific operational rules one might establish for flying a nuclear-powered airplane. I think it could be surely handled by proper flight discipline and by proper operational procedures and proper flight controls.

Representative PRICE. Thank you very much, General Keirn. Senator Anderson.

Chairman ANDERSON. General Keirn, in the ballistic missile race we sort of let Russia get out in space first and give us some tipoff on what they might have in missiles. Are we going to let the Russians get the first nuclear-propelled airplane?

General KEIRN. Senator Anderson, I hope not. I have an intuitive feeling myself that they are quite well along the road.

Chairman ANDERSON. Yes. I tried to get one of the distinguished people on the record the other day as to when the Russians might have one. I offered to put my guess on the record, and he preferred not to. Do you feel that there is a possibility of a Russian nuclear-propelled airplane—I don't ask you to answer this if you don't want to—within 2 years?

General KEIRN. I think there is a possibility of it.

Chairman ANDERSON. There is no possibility we will have one?

General KEIRN. I don't want to say they are going to but I think it is possible to do it.

Chairman ANDERSON. The way the trend is now going, it is a pretty safe bet we won't.

General KEIRN. Yes.

Chairman ANDERSON. I am happy to have you say that, because I was very much interested in one part of your statement where you said when we are ready for a test flight and we ought to make the test flight if it contributes. I agree with you very strongly. I am happy that you have said that. I judged you said it might be worthwhile building with existing materials.

General KEIRN. Yes, indeed.

Chairman ANDERSON. I don't recall just what page it is, but I certainly want to commend you on that, because I think it is worth building with existing materials in order that we may learn something about flight characteristics and possibilities. Later on, after we have it constructed, or if while we are building it, we obtain advanced materials, would that same plane possibly be able to use those advanced materials?

General KEIRN. The same powerplant will use them.

Chairman ANDERSON. Therefore, we would not be losing time, but gaining time by having something in the air?

General KEIRN. Yes, sir.

Chairman ANDERSON. You have no responsibility for this bad result so I am going to call your attention to this table that the committee prepared, showing from 1946 through 1951, when NEPA was finally folded up, we had only wasted some 20 or 30 million. That might not have been too large. But now we have an investment that runs, as I total these figures, through fiscal year 1960, $990 million. For purposes of comparison, if you ever happened to check to see what the total amount is involved in the development of a nuclear submarine and putting four or five of them in the water thus far, does it run to about the same figure?

General KEIRN. I thought it was in the same ball park, Senator, but I don't have the figures.

Chairman ANDERSON. I call attention to Admiral Rickover's testimony only a few days ago in which he said, "The total cost of the Navy nuclear program to date is $800 million." The total cost through 1960 of this nuclear airplane program is going to run around $990 million. We recognize that the problems of nuclear flight are probably a great deal more difficult than the problem of nuclear submarine propulsion, but it does seem that when we are up in the $990

million bracket we ought to do a little more than say, "Let us not test this air cycle until we get perfect materials."

You were asked if research and development would go on while this flight was being tried. I am asking you to testify about a field which you are not familiar with, but aren't we spending money for research and development of nuclear propelled submarines right now even though we have some in the water?

General KEIRN. I am sure we are and I am sure we should. I am sure we should continue our research and development effort when even we get a flight test program.

Chairman ANDERSON. We are spending this year $100 million on research and development on nuclear submarines, which is no small amount of money. The problem of trying to get these planes in the air, of course, is an enormous problem. I noticed the statement, if I can find it here again——

Representative PRICE. While you are looking for that statement, without objection the press release on calling the meeting and the chronological history and test charts will be introduced as a part of the record in this hearing.

Chairman ANDERSON. I was going to ask that you do that, Mr. Price, and I am glad you have done it.

(The press release referred to follows:)

JOINT COMMITTEE ON ATOMIC ENERGY, RELEASE NO. 235, JULY 21, 1959

A public hearing on progress of the aircraft nuclear propulsion program (ANP) has been scheduled for Thursday, July 23, it was announced today by Representative Melvin Price, chairman of the Subcommittee on Research and Development of the Joint Committee on Atomic Energy. In rescheduling the hearing, which was postponed earlier because of the death of Secretary Quarles, Representative Price made the following statement:

"We are distressed to learn that plans for a flight program for the nuclear propelled aircraft, which only 2 months ago appeared to be headed for high level approval, are now being shelved in favor of a continuation of the present policy of drift and indecision which has characterized the aircraft nuclear propulsion program from its very inception.

"We have tried our level best to be patient in the hopes that the Defense Department and the AEC would come to Congress with a firm program, looking toward flight testing of the direct cycle propulsion system which competent technical people, including the AEC's General Advisory Committee, are convinced is ready for proving out in actual flight.

"After 11 long years of discussing this matter in executive session with the Defense Department and the AEC, for reasons of national security, I believe the time has come for a public airing of this matter so that the American people can be better informed of the true facts of the situation.

"I am therefore scheduling public hearings for Thursday of this week in which we hope to bring out the major issues and questions involved. I believe that such hearings can be held without endangering the national security. On the contrary, I am convinced that the national security will, in fact, be enhanced by an informed public opinion."

Witnesses invited to testify at the hearings are: Maj. Gen. Donald Keirn, Director of the ANP project, Secretary of the Air Force Douglas, Gen. Thomas D. White, Chief of Staff of the Air Force, Secretary of the Navy Franke, Chairman McCone of the Atomic Energy Commission, Deputy Secretary of Defense Gates, and Dr. Herbert York, Director of Research and Engineering, Department of Defense.

The morning session of the hearings, beginning at 10 a.m., will be held in the Senate caucus room (room 318, Old Senate Office Building). The afternoon session, beginning at 2 p.m., will be held in the old Supreme Court Chamber of the Capitol (room P–63).

(Chronology and cost breakdown on ANP program, which were attachments to the above release, appear as appendix A, p. 113.)

Chairman ANDERSON. This is on page 10 of your prepared statement:

> With regard to a militarily useful powerplant, a negative argument has been advanced that military utility can be achieved only when turbine inlet air deriving its heat from the nuclear heat source equals or exceeds the turbine inlet air temperature contemplated for advanced chemical turbojet propulsion systems. This, in my opinion, is a fallacious line of reasoning.

Is that one of the things that you said would have to be your personal opinion, because that is not the opinion now of the Defense Department?

General KEIRN. I am not sure what the opinion in the Defense Department is. This has been advanced to me.

Chairman ANDERSON. We had an off-the-record session which you attended. That sort of persuaded me that there are people there who at least do not regard that as a fallacious line of reasoning.

General KEIRN. I think this is probably correct. It is my personal opinion.

Chairman ANDERSON. Your experience in this program persuades you that is a fallacious line of reasoning?

General KEIRN. My experience in the turbojet development since the first day this country has had turbojets tells me that.

Representative PRICE. I would like to point out that General Keirn has spent his entire career in the airplane development field. Is that correct?

General KEIRN. I have been an aeronautical engineer directing my attention to the propulsion of aircraft most of my career, since I took postgraduate work in 1937.

Representative PRICE. How many years?

General KEIRN. That is 22 years. I brought the Whittle engine to this country and started the turbojet program in this country.

Chairman ANDERSON. That may explain why the Joint Committee has quite a bit of confidence in your testimony and what you have to say. You said earlier on page 10 that—

> One issue of long standing is the usefulness of nuclear-propelled aircraft in the strategic role in the time period when ballistic missiles will be available in sufficient supply in our arsenal.

Do you think the desirability of a nuclear-propelled airplane bears any direct relationship to the number of ballistic missiles we may have in our arsenal or is it a desirable device in itself?

General KEIRN. I think it is both. I believe that General White may address himself to this problem of whether we should have a manned airplane program along with the ballistic missiles. I think that they are compatible systems. If you have the suitable manned aircraft strength in parallel, you might well not need quite as large an inventory of missiles. This is something that is out of my field of cognizance so I would like to make it clear this is just a personal opinion on my part.

Chairman ANDERSON. I was not trying to comment on how many ballistic missiles we need because I can recall going through an atomic stockpile some years ago and being told how ample it was for all our needs, and then we made quite a substantial change in our calculations.

All I was trying to say there was that when we developed the *Nautilus*, we did not have in mind the possibility of the Polaris system. It was only after we had the *Nautilus* in the water for a substantial time that the Polaris system was decided upon and devised. It could be that after we had a nuclear powered airplane in the skies, there might be some suggestions come to us there as a manna from heaven like the Polaris did—if these devices ever come from heaven.

General KEIRN. It is very possible, Senator.

Chairman ANDERSON. You do not believe that the nuclear-propelled airplane is a desirable thing without regard to the size of various other stockpiles?

General KEIRN. I do.

Chairman ANDERSON. I want to commend you very particularly for the last sentence in the middle paragraph on page 11:

> Thus, it is impractical, if not impossible, to establish a meaningful criteria nuclear propulsion systems on the basis of turbine inlet temperature alone.

I did write down, "Good for you" on the side of the testimony sheet.

The statement that Mr. Durham elicited from you a moment ago with reference to the fact that it is not a saving procedure to wait until all of the materials are perfect before you try this out, you said on page 12:

> Waiting for the full performance cores before initiating such a flight test program needlessly delays the program, and in the long run is a more costly procedure.

I think that is true of most weapons systems, isn't it? They are not all born perfect?

General KEIRN. That is right.

Chairman ANDERSON. Some of them have had a little development done on them. It would not be remarkable if the nuclear propelled airplane needed some development.

General KEIRN. It surely will.

Chairman ANDERSON. I think you said a very truthful thing when you said it might be a more costly procedure. I would like to go on a long time. I only want to say to you that I appreciate this testimony. I think it is a fine statement. I am sorry that I think I see a decision to slow down still further a program that I think should have been accelerated, and which you have manfully tried to keep moving. I commend you for your efforts.

General KEIRN. Thank you, sir.

Representative PRICE. I will say, Senator, that if we eventually get a plane in the air, it will be because General Keirn prevailed against a legion of doubters in the Department of Defense. He has fought vigorously for this program, and I want to reiterate the commendation I made earlier because I have known of the struggle he has had in the capacity in which he now serves.

Mr. Hosmer.

Representative HOSMER. General, I think we are having a little semantics trouble in relation to this early flight. I would like to get that straightened out in my own mind.

Getting the engine in the air in an airframe for the purpose of flight testing the engine is one thing. Getting it in the air in a military prototype aircraft is another thing, is that correct?

General KEIRN. Those are two considerations that can be separated.

Representative HOSMER. When we are talking about early flight, I think your argument is that if we go to early flight that it should be done in a new prototype military aircraft.

General KEIRN. This is my personal feeling.

Representative HOSMER. The reason which underlies that is the money you put in there will not be lost because you have acquired the beginnings of a military airframe, is that correct?

General KEIRN. Only partially.

Representative HOSMER. Will you explain?

General KEIRN. As I pointed out, after we have very carefully studied both approaches, it has been our conclusion that the new airplane, designed specifically for nuclear propulsion, is the preferable airplane for the flight test purposes. It is perhaps a fortunate gratuity that that same airplane will be useful in evaluating the military utility of the airplane.

Representative HOSMER. Insofar as the determination that the engine will propel an aircraft and many of the qualities which it will produce, that can be ascertained from any kind of airframe that will carry it up in the air, can it not?

General KEIRN. I am sure that you could ascertain the fact that it would propel an airplane. I am not sure that you could ascertain how well it would propel the airplane or how well it would serve the purposes in a useful airplane.

Representative HOSMER. Doesn't that get us back to probably the fundamental difficulty that underlies this long line of work here as to exactly what you are going to do with the airplane after you get it. In other words, the military significance of the craft.

General KEIRN. Yes.

Representative HOSMER. You have discussed on page 10 in relation to the missiles and say that is a matter involving human judgment and so on.

General KEIRN. Yes.

Representative HOSMER. Hasn't it been the history of this thing that although like the development of the propulsion plant for submarines at the time the work began it was a rather noble idea and they were pretty sure there would be some real use for it, but maybe in the beginning days they had not settled down on any theories of the actual use of the propulsion plant? As it turns out there have been pretty good uses for naval propulsion. But in the aircraft field we are still in the stage where there is doubt and speculation as to putting it to a militarily useful purpose.

General KEIRN. From a military standpoint there is a doubt as to the specific mission that such an airplane would perform.

Representative HOSMER. That is right. I think Senator Anderson mentioned its relationship to ballistic missiles and where it would fit in there. I have no doubt that this country could produce large herds of two-headed bulls if we had reason to do so and we could do it pretty fast. I think probably underlying the accusations of delays in this program is the fact that there has not been a clear-cut military purpose to which nuclear propulsion in aircraft can be devoted. Isn't that a fact?

General KEIRN. I am sure that if there were an agreed upon specific operational requirement using the present terminology, that

there probably would not be as many questions raised with regard to the course of action which you take.

Representative HOSMER. You mentioned the closed or indirect-cycle engine. That would be equally capable of development, I think, from the purport of your testimony, as the direct cycle.

General KEIRN. I believe I said that there were a number of materials problems yet to be solved. We have a great deal of work to do on certain aspects of the program. So success will be achieved at some period later than the period in which we believe we can achieve useful machinery in the direct cycle.

Representative HOSMER. But if a real necessary use were found for the indirect cycle, you could go to work on it and have what you call a specific operations requirement rather quickly?

General KEIRN. No; I would not say rather quickly. As I say, the progress up there is exceedingly promising but it will not lead us to a propulsion system for an aircraft as quickly as will the direct cycle.

Representative HOSMER. Even a low performance aircraft.

General KEIRN. I think the answer is "Yes." I don't know. You are changing the ground rules on me a little bit, but I think that any kind of a propulsion system that will fly an airplane if you apply the same ground rules to the direct cycle as you do to the indirect cycle, whether it is a low performance or high performance airplane, we could get there first with the direct cycle.

Representative HOSMER. I think that is all.

Representative PRICE. Thank you, Mr. Hosmer. Mr. Bates.

Representative BATES. General, I am trying to assess in my own mind the importance of this project. I notice here on page 6 you say the Joint Chiefs of Staff do not have a specific operational requirement for it. Let me ask this question. I understand that before this program over the years fully gets underway, the cost will be approximately $5 billion plus or minus, depending on how extensive it is. If today the Congress was to appropriate $5 billion to the Air Force, would the money be spent for this purpose, or are there other items of a much higher priority nature that would absorb the money which the Congress would appropriate?

General KEIRN. I am sure that one always puts his money on the elements that we need first to be sure that our country is continuously defended. Certainly some money would go on this and some money is going on this program. But the Air Force would not, even if they had the $5 billion, that you referred to, start in on a weapons system on this program. We want to fly a nuclear-powered airplane and find out how we can best direct our efforts in the production of a weapons system. We think the CAMAL presents a useful type of weapons system. We are not convinced that it is the kind we want to inventory. We won't be convinced that this is the kind that we want to inventory until we know how you can operate a nuclear-powered airplane and how much it is going to cost us to operate, how much it will cost to inventory. So the Air Force is not proposing to go into a weapons systems development program at this time. But the quicker we get to a flight test airplane the quicker we will be able to say whether it is definite that we must do this.

Representative BATES. We are talking today about the possibility or the urgency of speeding up this program.

General KEIRN. Yes.

Representatives BATES. That is the essence of the discussion here. My question, then, is this: If the funds in the amount requested were given to the Air Force and they had their choice of putting it into this or into other things into which part would they put the money? Let us put it this way. I have seen a list of requirements from the various services for the need for additional funds before the Appropriations Committee. I recall this was not listed in that urgent classification.

General KEIRN. My impression was that there were some funds for this. I won't say for sure. I get your point, Mr. Bates. I know what you mean. I can only suggest that you ask this question of the Secretary, and to my chief.

Representative BATES. I think that is right.

General KEIRN. I know that one is always pressed with what do we do today to keep the wolf from the door, and what portion of it can we afford to make damn sure he does not reach our door next year.

Representative BATES. That is the problem we have with all the services. We have had them all before our various committees, Armed Services and Atomic Energy. They all need more. It is a question of priority. I wondered how this fits in the order of priority. I think probably General White and the Secretary can answer the question.

General KEIRN. I think they can answer the question better than I.

Representative DURHAM. I might say we gave the Air Force $9 billion this year, and not a line-item basis for the development of airplanes and missiles. It was not authorized by any authorizing committee. It was done by the Appropriations Committee. We gave them $9 billion this year.

Representative PRICE. Mr. Westland.

Representative WESTLAND. General, I believe I have just two questions. If your requirement was for less than a militarily useful nuclear-propelled aircraft, how soon do you feel you could get one in the air?

General KEIRN. Our program has been so specifically oriented toward a propulsion system that will be useful that the kind of airplane we are proposing could be built just as fast as you could build anything else.

Representative WESTLAND. In other words, would a less than militarily useful aircraft not be built any more quickly than a militarily useful aircraft?

General KEIRN. I think at this stage of the game that is correct, if when you say militarily useful you will accept the kind of airplane which we have proposed as being militarily useful.

Representative WESTLAND. You are talking about a high subsonic speed aircraft and carrying a lot of weapons?

General KEIRN. That is correct.

Representative WESTLAND. Which is a pretty tough criterion to follow. I am just asking whether if you did not have all those requirements, could you have a nuclear-propelled aircraft flying within a shorter period of time?

General KEIRN. I don't believe that we could have one. The propulsion system has in the past paced the program. Right now we either start the airplane now or the airplane will be pacing the situation.

Representative WESTLAND. This contract with Convair, I am a little confused on it. In one part it sounds as though you are asking them to build an air frame for the purpose of a nuclear-propelled aircraft, and in another part of your statement it sounds as though the design has not been finalized, and is still sort of in limbo.

General KEIRN. They have not been authorized to commence detailed design of this model 54 airplane. During the competition phase, they were authorized to do a preliminary design and come up with recommendations for an airplane that would provide this flight test vehicle and at the same time provide a prototype for the CAMAL system. This design was submitted at the time the competition was completed. At the present time the Convair Co. is only authorized to continue examination of this and modifications thereof, working in conjunction with the General Electric Co., to provide guidance for the integration of the powerplant with the airframe. But they have no authorization yet to begin detailed design or construction. In other words, a phase 1 contract has not been issued.

Representative WESTLAND. In other words, they submitted a proposal that was satisfactory to you for an airframe for a nuclear-propelled aircraft.

General KEIRN. That is correct.

Representative WESTLAND. Why have they not been authorized to go ahead with it?

General KEIRN. We have no authority yet to proceed with the flight test program.

Representative WESTLAND. Who has not?

General KEIRN. The Air Force has not.

Representative WESTLAND. Where do you get that authority?

General KEIRN. From the Department of Defense.

Representative HOSMER. Does this CAMAL concept have possibilities of expansion into the transonic range?

General KEIRN. The direct cycle?

Representative HOSMER. No, the CAMAL concept.

General KEIRN. No. I am not sure what you mean by transonic, but it is specifically a subsonic airplane. There is a major change in the aerodynamic characteristics of an airplane when you build one to pass through the sonic area.

Representative HOSMER. Would that mean, then, that this system, if it were developed, would become obsolete if ANP technology came along so that you could power supersonic aircraft?

General KEIRN. If you could supersede this particular weapon system with another one that would have better military performance, I would say it would render it obsolete.

Representative HOSMER. If you can go transonic, you can get better military performance, can you not?

General KEIRN. Perhaps.

Representative HOSMER. You started out with your first general operations requirement with a transonic concept.

General KEIRN. A supersonic concept.

Representative HOSMER. Then it was downgraded to meet the technology.

General KEIRN. That is correct.

Representative HOSMER. I suppose if the technology advances, it would be upgraded again, is that right?

General KEIRN. Possibly.

Representative HOSMER. Then we have a possibility of losing a lot of money here on an early flight concept of a military aircraft that could be made obsolete very rapidly.

General KEIRN. If you had a CAMAL weapon system, it would depend on whether that system became obsolete. That system may have a long life. I think this is a question you could address to some of our operational analyses. They feel that system may have a reasonably long life.

Representative HOSMER. What is in my mind is that your statement that you would save money by going to a military prototype airframe may not in fact work out that way.

General KEIRN. My personal opinion is that you will get to whatever kind of a characteristic you want in a nuclear-powered plane quickest and cheapest by getting going with this flight airplane right today.

Representative PRICE. We did not wait for the *Skipjack* in the submarine, did we? We went ahead with the *Nautilus*, didn't we?

General KEIRN. Yes, sir.

Representative PRICE. Thank you very much, General Keirn. You have made an excellent witness and we appreciate having your testimony this morning.

General KEIRN. Thank you very much, sir.

(The detailed report by General Keirn referred to on p. 4, follows:)

AIRCRAFT NUCLEAR PROPULSION PROGRAM STATUS

MANNED AIRCRAFT NUCLEAR PROPULSION PROGRAM [1]

In discussing the current status of the U.S. aircraft nuclear propulsion program, and in considering various proposed approaches for the exploitation of nuclear power for aircraft, there are certain concepts, philosophies, and issues which have a direct bearing on the situation. These factors may be consolidated in the answers to the following questions:

1. What are the characteristics of ANP which provide justification for a program of the magnitude required to achieve success; and a corollary to this question, what is a "useful" system?
2. What are the problems to be solved in developing practical aircraft systems, and what is the best course of action to finding solutions to these problems?
3. What bearing does the current technological state-of-art have on the possible applications and development courses of action?
4. What is the ANP time schedule and what are the funding requirements?

Unless the first question is properly answered with a clear-cut definition of the ultimate objectives, the remaining three questions have little significance except from a generalized point of view. It is difficult to delienate problems, schedule and fund their solution, or relate them to current status if the goal is nebulous. It is, therefore, necessary to properly orient ANP with respect to its potential future role in the national defenses, and keep this orientation in its proper prespective relative to other systems which would be available. To accomplish this orientation, a realistic appraisal of the advantages offered by ANP is fundamental. Basically, nuclear power replaces only one feature of conventional aircraft—the chemical fuel. Independence from the limitations imposed by chemical fuel create three specific advantages which ANP can exploit and which cannot be duplicated by conventional aircraft. These advantage are:

[1] Portions of this detailed report by General Keirn were deleted by the Department of Defense on the grounds of national security, following clearance of the full report, without deletions, by the Atomic Energy Commission.

1. Unlimited range which can be translated into either distance, endurance, or both in combination. The employment of this characteristic permits Zone of Interior basing without the burdens imposed by tanker aircraft inventories, oversea base logistics, defenses, and political considerations; it permits an airborne alert with its connotation of immediate retaliation and invulnerabilty; it permits omni-directional approach to the penetration problem with the obvious advantage of choice of penetration route for minimum exposure to enemy defenses; it permits flexible and positive timing, control, and target assignment and creates an imposing defense burden on the enemy.

2. Payload growth potential independent of range: ANP aircraft can be designed for large payloads at no sacrifice in range, and can increase payload directly with propulsion thrust to weight ratio improvements. Chemical or conventional aircraft weights, on the other hand, increase nearly exponentially for increased range with a constant payload; or, given a particular design, must sacrifice range for increases in payload.

3. Continuous low altitude penetration capability: Chemical aircraft are extremely limited in range at low altitude by virtue of the tremendous fuel consumption required. It is pertinent to point out that speed and altitude are not characteristics which are improved by ANP except at low altitude where operation at high speed results in the extreme range penalties for conventional aircraft.

In considering the application of these characteristics to possible useful military systems, one could certainly envision cargo and transport aircraft with tremendous capacity and extreme ranges; or patrol aircraft such as used on the DEW line and for antisubmarine duty. Such applications would obviously have their place in the future, but these specific applications fall far short of being competitive for the development resources required when compared against more conventional systems for doing the same missions.

Only in the strategic mission area does the payoff appear to justify the initial development cost. Only in this area is it possible to place a value on such things as the instant retaliatory capability and invulnerability achieved through airborne alert, the independence of oversea bases, the reduced aircraft inventory requirements, the omni-directional attack, the on-the-deck penetration, the high warhead capacity, and the complete flexibility of operation. These, then, are the characteristics of ANP which indirectly must justify the program. By the same token, the strategic applications which make the most effective use of these characteristics also permit the best exploitation of ANP.

The much discussed CAMAL weapon system makes effective use of all these characteristics. CAMAL stands for continuously airborne missile-launching and low-level penetrating weapon system. The operational concept of CAMAL is illustrated in figure 1. With its unlimited range and tremendous endurance, limited only by crew fatigue, each CAMAL bomber could remain airborne for a week at a time, or more, permitting the Strategic Air Command to keep a large percentage of its bombers continuously airborne. These bombers, fully armed and always ready for instant retaliatory action, would be able to cruise anywhere in the world, out of reach of sudden destruction on the ground by surprise attack or sabotage. This would allow us to instantaneously react to international developments through our ability to rapidly deploy the mobile force anywhere in the world and at the same time continuously maintain direct command control over such force. Each airplane can carry several long range ballistic missiles to be launched against enemy targets long before the airplane penetrates the enemy's defense perimeter. In addition, the CAMAL bomber can carry high yield bombs or short range missiles. Nuclear power will enable it to penetrate enemy territory at low altitude and high speed, undetected by long range radars and thus relatively secure from interception by enemy fighters. The CAMAL could start this penetration from any direction and follow an evasion path to any taret, without limitation of range. It could place over the enemy's heartland men to exercise judgment and followup missile attacks by aerial bombardment, either of targets left untouched by missiles, or new, previously unsuspected targets.

The CAMAL concept may be applied to either subsonic or supersonic nuclear aircraft. Subsonic applications could be available earlier, however, and would provide the know-how required before proceeding toward supersonic versions. Ground alert strategic systems are also possible, with some capability to trade shielding for increased payload. Such systems, however, are less attractive by comparison with higher flying and faster conventional aircraft which are also

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on ground alert, and which may have adequate range via great circle routes. With regard to the other possible applications, the technology which produces these strategic systems will be directly applicable, and may be employed at any time requirements are indicated.

In proceeding with a development program toward any of the weapon systems implied herein as an objective, it is natural to raise the second question of "what must be done in the development program and how can it be done the most efficiently?" In this regard, it is helpful to discuss the normal, standard sequence of events which are followed every day in this country during the process of developing any new concept. Basically, these events, or steps, entail:

1. Theory establishes the basic feasibility of the concept, or reveals what must be learned before such feasibility can be established.
2. Preliminary design work defines the scope of task, reveals further unknowns to be determined, and establishes the requirements for laboratory and experimental solution. Sometimes the tools required to determine these solutions are not in existance, and must themselves also be designed anew.
3. Working models, mock-ups, or so-called bread board arrangements demonstrating the concept are then constructed to serve as a guide to the design of a prototype, but still experimental model.
4. Rigorous testing of the model, both in the laboratory and under simulated use conditions reveal the merits and short-comings of the design, and provide the basis for definitized specifications for production versions.

In applying the above steps to any new development, it is necessary to provide timely solutions to all elements which contribute to the finished product, if time and money are not to be unnecessarily wasted through having to shelve much of the work while waiting for some key element or problem to be developed or solved. This implies concurrent development work in a great number of the problem areas.

In the manned nuclear aircraft program, the key factors requiring attention may be grouped as follows:

1. The powerplant must be developed. This includes:
   - Dev of high temp fuel materials
   - Dev of turbomachinery
   - Solution of integration problems—reactor/engines
   - Refinement & proof of shielding
   - Dev of practical controls
   - Determination of installation requirements
     - cooling
     - ducting
     - mounting points, loads, clearances (influenced by fuselage flexing under vibration and maneuvering accelerations)
   - Establishment of powerplant performance under flight altitudes, speeds, loads, & attitudes.
     - thrust available
     - control response
     - transition behavior
     - afterheat removal
     - engine-out behavior
2. Maintenance & handling equip & procedures must be determined. Areas of analysis, design and/or development:
   - Installation & removal equip for powerplant & A/C systems
   - Effects of aircraft activation on procedures & equip
   - Quick-disconnect requirements
   - Afterheat removal
   - Emergency equip & procedures
   - Special facility requirements & design criteria
   - Aircraft handling equip
3. Shielding design must be refined through:
   - Exposure to design radiation fluxes
   - Shaping for minimum weight
   - Selection of n/γ ratios & degree of division
   - Evaluation of internal equipment shielding effects
   - Evaluation of shield augmentation requirements as related to ground handling.
   - Design & test of duct & cable shield penetrations

4. Environmental development testing & evaluation of location requirements of aircraft subsystems for max-reliability must be conducted. Typical of these are:

Dev A/C:
- Air conditioning
- MTC (airbase & short range nav & comm equip)
- Secondary power
- Flight control systems

Wpn Sys:
- B&N
- Long range communications
- ECM and IR equip
- Active defense equip

5. Demonstration of the practicability of nuclear powered aircraft through the effective integration of all the above factors into a properly designed aircraft system. This practicability is confirmed through:
- Sustained flight on nuclear power only
- Demonstration of reasonable & effective handling procedures
- Development of acceptable flight techniques
- Verification of design solutions
- Verification of operational capability, reliability, and safety

Much of the above can be, has been, and will be accomplished through ground development programs. There is a limit to what can be done through ground test, however, and once the basic design parameters have been established—as is the case—it becomes necessary to introduce the flight aspects for concurrent flight and ground development. There is an interdependence of ground and fight produced influences on the factors outlined above which can be solved only by an iterative process, and if valuable time is not to be wasted, the two must be evaluated together.

The status of the current ground development program for ANP is such that a nuclear powerplant, suitable for flight, with inherent growth potential for military usefulness, can be scheduled to be available on a time scale no later than that which would be required to provide a suitable flight development vehicle.

Since the inception of our hardware research and development program in 1951, we have accomplished design and experimentation on reactor components, turbomachinery and the basic nuclear areas peculiar to nuclear propulsion. We have provided to the propulsion contractors and airframe contractors those facilities which are necessary to the definable development tasks. We have accomplished the necessary configuration studies in both propulsion and airplane areas and have selected what we consider to be the initial useful configuration in both areas. In the case of the direct cycle, in which propulsive air is heated directly by the nuclear reactor, the design of a ground test propulsion system has been completed. We operated what is known as Heat Transfer Reactor Experiment No. 1 (HTRE 1), shown in Figure 2, Shown in Figure 2 is the test facility with all of its test piping, air ducting and facilities for both nuclear and chemical operation. At the right are the modified engines connected by ducts to the reactor located in the large central tank. The ground test equipment is mounted on a dual flat car so that it can be drawn between the test and maintenance areas by a shielded locomotive shown at the extreme left. HTRE–1, however, was a water moderated system which did not contain any flight system characteristics. It was later modified for testing of various fuel elements and moderators. In this configuration, we call it HTRE–2. It was followed by HTRE–3, this past November. Figure 3 shows HTRE–3 stripped of all its test equipment and supporting structure.

In addition to the Heat Transfer Reactor Experiment Tests, we are conducting dynamic testing of various promising fuel element materials suitable for flight application, using facilities such as the Engineering Test Reactor at the National Reactor Testing Station. Tests have been extremely encourging, and give us increased confidence in our ability to fly.

The General Electric direct cycle system is not the only powerplant concept under development. At Pratt & Whitney in Middletown, Conn., we are making significant strides with the indirect cycle system. The indirect cycle makes use of higher density heat transfer media which remove energy from the nuclear reactor and transport it to the engines where it is added to the propulsive air through heat exchangers. This cycle offers the potential for attractive performance in both subsonic and supersonic applications, but its development status is behind the direct cycle system. Also at Pratt & Whitney, we have built

the necessary industrial and testing facilities, and through the development programs at P&W and at Oak Ridge National Laboratory, have developed a sound technological base.

In the area of shielding, we have built and flown a one MW shield test reactor in a modified B–36. This aircraft, shown in Figure 4, along with special towers used at Oak Ridge for shielding experimentation, performed 47 flights conducting 35 megawatt-hours of testing over a two-year period. As a result of these experiments, and others, the correlation between theory and practice has been narrowed significantly. In Figure 4, predicted performance for given tests are shown as solid lines, and the actual test data are shown as squares and triangles.

In the area of radiation effects, dynamic testing of aircraft-type components in a nuclear environment has indicated that flight with currently available materials is possible. A summation of where we think we stand in radiation tolerance of susceptible elements for various aircraft components and equipment is shown in Figure 5, which illustrates expected life of currently available off-the-shelf materials in the nuclear environment.

Consideration has, therefore, been given to what the most suitable flight development vehicle would be. In a manner of speaking, the flight aircraft could be viewed as a facility for flight development, more than just an aircraft. As such, this "facility" would cost less to provide and place into operation than has been and will be required to support the ground development phases. As in any facility, the design specifications are dictated by the job to be done. Typical characteristics and/or requirements established by the "job to be done" include:

1. Maximum safety of operation (independent of nuclear power plant during all flight operations).
2. Sufficient chemical range to operate over ocean or isolated test areas from inland bases.
3. Adaptable to a variety of nuclear powerplant cycles and configurations.
4. Maximum design margin to accept possible powerplant weight and thrust adjustments.
5. Capable of flight testing powerplant through its complete flight spectrum
6. High degree of applicability to ground support and operational assessment.
7. Ability to demonstrate the basic advantages offered by ANP—range, endurance, payload, and high-speed low-altitude operation.

In fulfilling these requirements, both modified existing aircraft and new aircraft were considered. It was almost immediately determined that the modified aircraft, either land or seaplanes, were extremely marginal and were generally unsuitable. They appeared to offer little more than a flight demonstration capability, bearing little relationship and having little applicability to the problems requiring solution. In addition, the cost of modification would ultimately have to be added to the total job, in that most of the development tasks would still have to be done in a new aircraft.

A new aircraft, on the other hand, could be designed to accomplish all the requirements listed above—and more, if it bore a resemblance to a possibly useful military system. Because of this, the Air Force proposed flight development program embodies a new aircraft having the growth capability to perform the CAMAL mission discussed earlier.

The question frequently arises as to why so much emphasis is placed on CAMAL. In the early paragraphs of this discussion the various advantages which ANP has to offer were enumerated. In considering the CAMAL mission, all of these advantages are manifested in one form or another. Development of an aircraft capable of performing the CAMAL mission, therefore, also permits the early evaluation and exploitation of these ANP characteristics. Development of such a CAMAL oriented aircraft therefore appears to make the most sense, particularly since the same aircraft can effectively accomplish the flight development task.

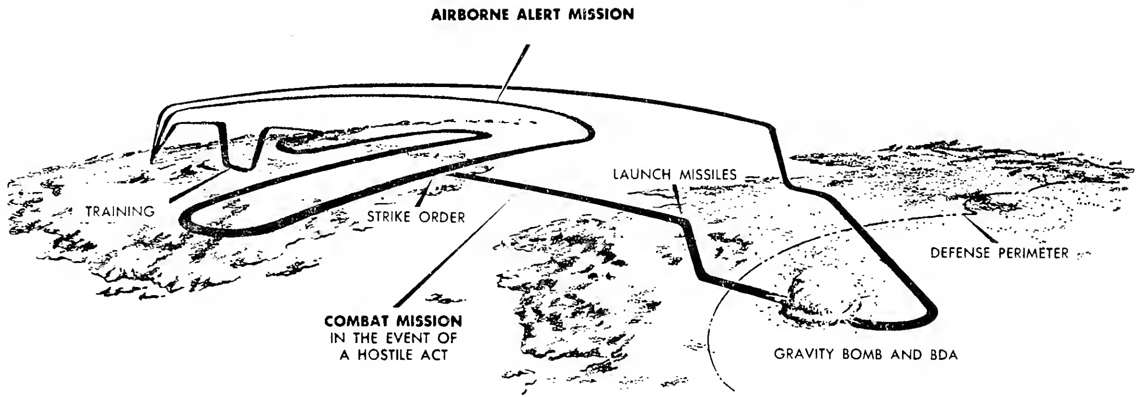
We have examined the hazards to the public from such a ground and flight development program. By using our accident experience with all our experimental jet aircraft, we have analyzed the additional risks that would have been imposed had these aircraft been nuclear powered. We have actually burned fuel elements simulating a crash and fire to determine atmospheric diffusion characteristics. Through such analyses and tests we have devised tentative operational procedures, and have determined the requirements which should be imposed upon flight test or operational bases. In conducting these analyses, we have employed what we believe to be pessimistic assumptions with regard to all criti-

cal parameters affecting nuclear hazards in event of accident. We have concluded that proper selection of bases and appropriate flight controls will reduce the hazard to the public to levels not materially exceeding those associated with the operation of other military aircraft and, because of these controls, to levels of hazard perhaps markedly less.

The schedule and funding for the Air Force proposed flight development program is dependent, of course, on funds availability and program decisions. It could be possible, however, to conduct nuclear flight testing in as few as 4 years. A still fast, but somewhat more leisurely pace would require 5 years. Total cost over this period, which included only $150 million for the airframe program, would be about $1 billion. No matter when we start a flight program, however, be it now or 2 years from now, the cost will still be another billion dollars. The cost cannot be reduced by merely postponing it. Proponents of flight program deferal imply we should defer until we have something better. This also can be a never-ending approach. Only by establishing a realistic and achievable objective, and proceeding unwaveringly toward that objective, will the successful exploitation of ANP be achieved within a reasonably early time scale.

FIGURE 1

CAMAL MISSION CONCEPT



AIRBORNE ALERT MISSION

- WEAPON SYSTEM BASED ON N.A. CONTINENT
- EXTENDED RANGE AND ENDURANCE
- ALL WEATHER OPERATION
- LARGE PORTION OF FORCE CONTINUOUSLY AIRBORNE
- MISSION MAY BE ACCOMPLISHED OVER FRIENDLY TERRITORY OR WATER
- CAPABLE OF LOW LEVEL TRAINING ON EACH PATROL MISSION

COMBAT MISSION

- INSTANT REACTION
- ALL WEATHER OPERATION
- WORLD-WIDE TARGET COVERAGE WITH HIGH YIELD WEAPONS
- MISSILES LAUNCHED OUTSIDE ENEMY DEFENSES
- FOLLOW UP ATTACK AT LOW LEVEL WITH BOMBS & BDA
- EXTENSIVE PAYLOAD FLEXIBILITY

FIGURE 2

HTRE No. 1

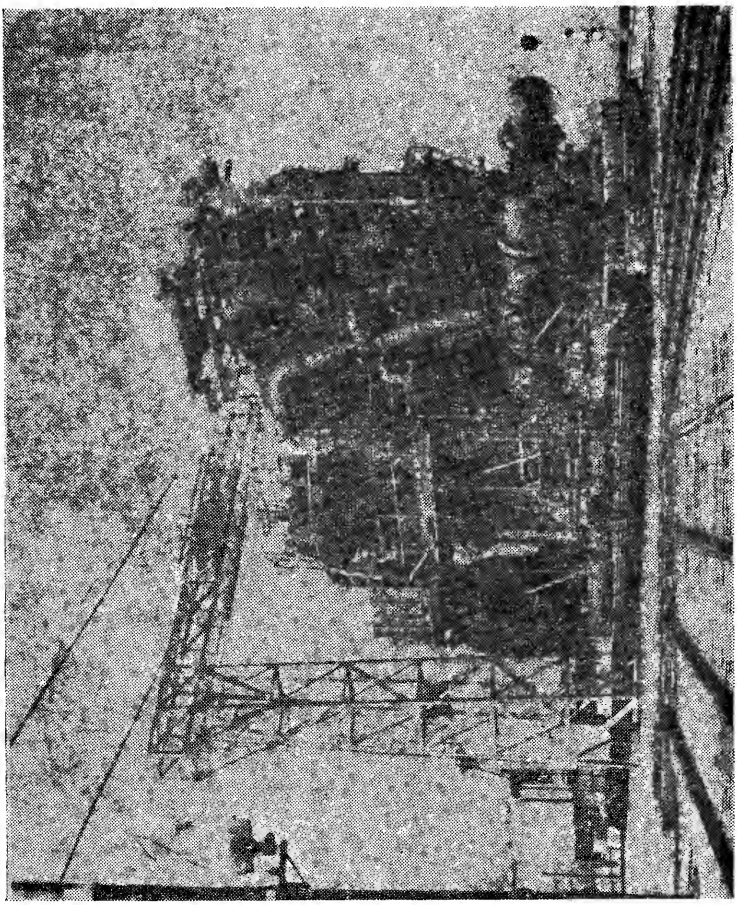


FIGURE 3

HTRE NO. 3

KEY COMPONENTS

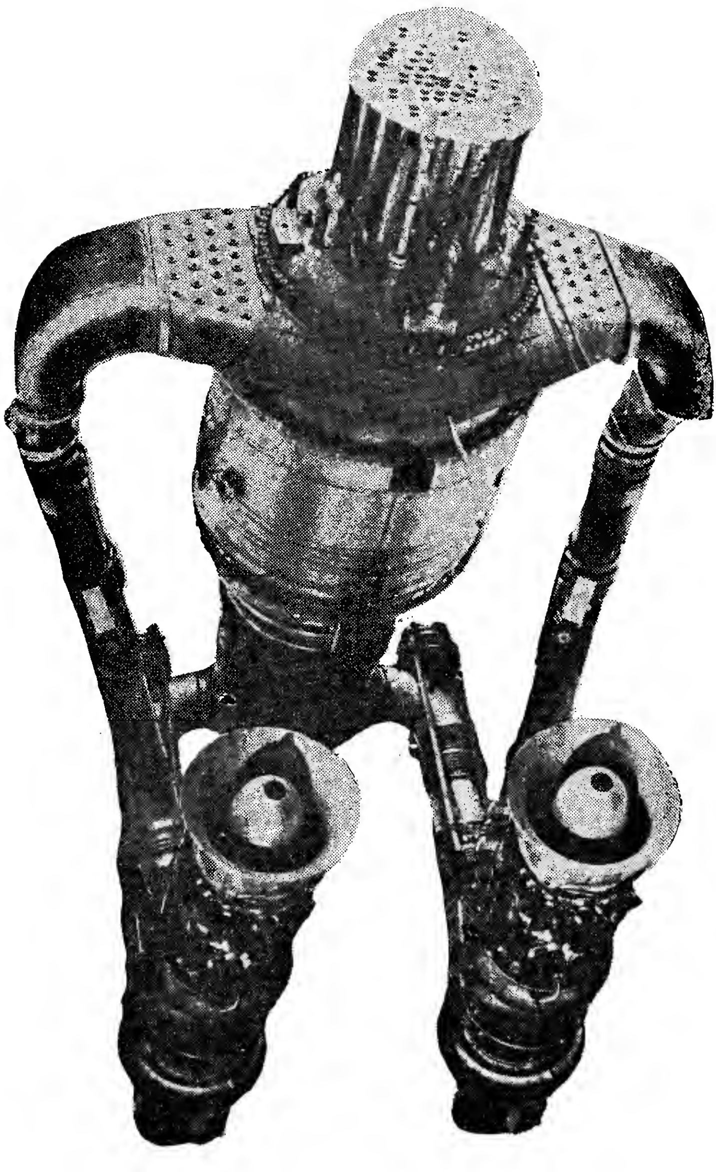


FIGURE 4

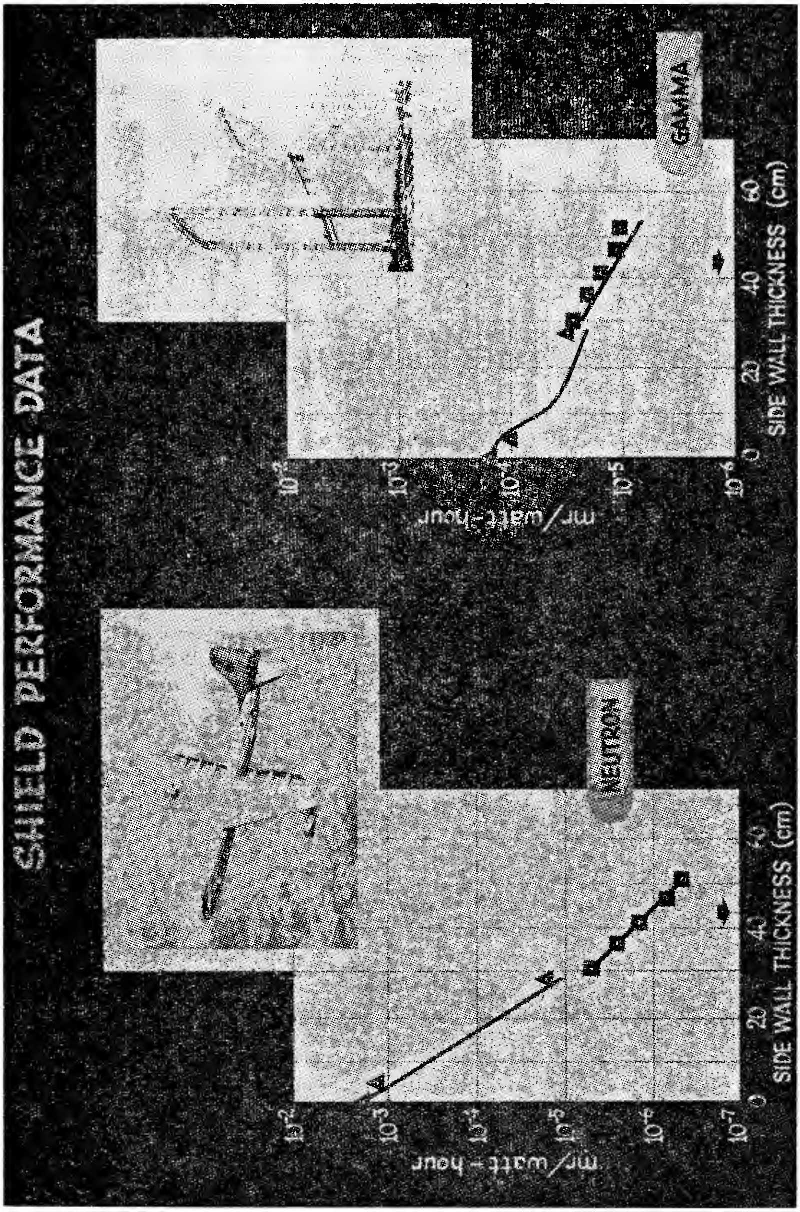
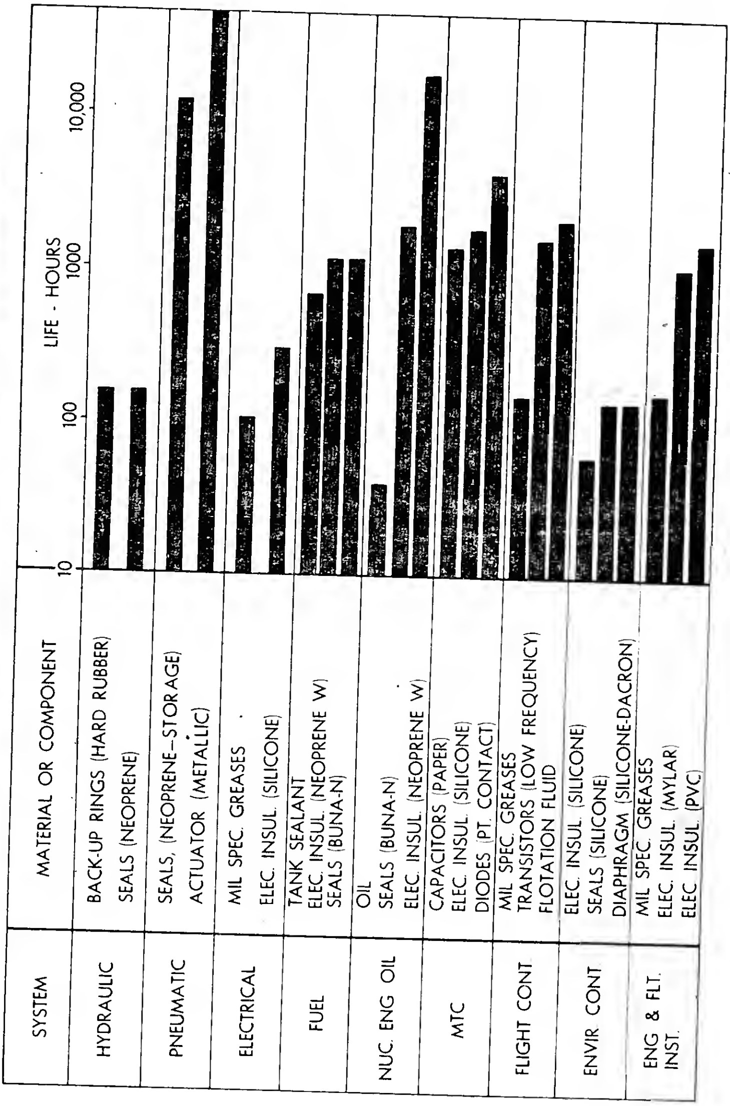

SHIELD PERFORMANCE DATA
NEUTRON
mr/watt-hour
SIDE WALL THICKNESS (cm)
GAMMA
mr/watt-hour
SIDE WALL THICKNESS (cm)

FIGURE 5

SUMMARY OF AIRCRAFT SYSTEMS STUDIES



Representative PRICE. The next witness will be Mr. Philip Taylor, the Assistant Secretary of the Air Force for Materiel.

STATEMENT OF PHILIP B. TAYLOR, ASSISTANT SECRETARY OF THE AIR FORCE FOR MATERIEL

Mr. TAYLOR. Thank you, Mr. Chairman.

Representative PRICE. Would you proceed with your prepared statement.

Mr. TAYLOR. Mr. Price and gentlemen, nuclear aircraft propulsion has engaged major effort by the Air Force over a period of 10 years and has cost many hundreds of millions of dollars. During this time the program has been redirected several times. However, overall, a great amount of progress has been made. We are close to the point at which we can become definite about flight testing, although at this time we are still not clear as to the exact military use.

As you are well aware, two types of powerplants show technical feasibility—one, a direct cycle which provides direct heat to a turbojet engine; and the other, an indirect cycle which transfers heat through a liquid metal. Each cycle has its advantages and disadvantages, and both require a rather large amount of shielding for protection of the crew and maintenance people. It can be assumed that both cycles will continue in development and added performance will be acquired as time goes on.

In all aircraft powerplants, flight test is necessary to determine airplane and engine-matching performance, and particularly in the case of nuclear propulsion to determine the problems connected with radiation for both the crew and the mechanical parts. This is a most important part of the use of nuclear propulsion. Such factors as the aircraft shield system, the effect of radiation environment created by the powerplant, the maintainability and supportability of the nuclear aircraft, the logistics of nuclear propulsion, the flight techniques and procedures, basing problems, and public safety are among the items which can be determined by flight test.

Nuclear propulsion is important to military considerations because it provides the only known means for unlimited range and endurance which are characteristics of great value to many military requirements. Unfortunately, among these desirable characteristics powerplants to date have had undesirable characteristics of extremely high weight per unit of power, due to shielding requirements, and limitations in accessibility due to radioactivity. The weight of course is largely influenced by the amount of shielding necessary to protect the personnel. It is reasonable to project reductions in specific weight with the discovery of better shielding materials and with the increase of the temperature of operation of the gas turbine engines. However, the nuclear powerplant can be applied only to a relatively very large airplane because the shielding itself is of great mass.

Although it is not possible to determine at this time the exact role of the nuclear-powered aircraft, its characteristics of unlimited range and endurance constitute a strong military requirement which must be developed to keep the military in a position to utilize this unusual characteristic when and wherever it may be found to be important. Already we have several proposals in which the nuclear powerplant

plays an important part. One of these is the CAMAL project, which constitutes a mobile carrier which can remain airborne for long periods of time and from which missiles can be discharged into enemy territory from any direction.

The Air Force believes that a flight test of a nuclear powerplant would be a useful experiment which should be undertaken as soon as a powerplant with characteristics within the military useful flight spectrum is available. Although we regard the development of nuclear-powered flight as important for military purposes, it must take its proper place in relation to other military projects of high priority.

The last time the Air Force appeared before this committee, it was felt that the reactor being developed by General Electric would soon justify going ahead with flight test. We now feel that it may be wiser to wait until better performance is demonstrated.

At this time, development of both the direct cycle and indirect cycle look promising with regard to increased temperature of operation, and, therefore, increased powerplant performance. The current plans include continued development of both cycles during the 1960 fiscal year. Also, design analysis is continuing on a suitable test airplane which will be sufficiently versatile to accept any of the nuclear powerplants under consideration.

It is expected that by the end of the fiscal year another examination will be made of the available powerplants, which may lead to a flight test oriented program. Consideration of the availability of funds from the 1961 budget will also influence this decision.

That completes my statement.

Representative PRICE. Thank you, Mr. Taylor.

I would appreciate it, Mr. Taylor, if you would remain in the witness chair and the committee would then hear from General White, and after General White completes his statement we can direct any questions we may have to the two of you.

Mr. TAYLOR. Very good.

Representative PRICE. General White, will you come forward, please? The next witness will be Gen. Thomas White, the Air Force Chief of Staff.

STATEMENT OF GEN. THOMAS D. WHITE, CHIEF OF STAFF, AIR FORCE

General WHITE. Mr. Chairman and gentlemen, Secretary Taylor has just presented the broad outlines of the Air Force position concerning the manned nuclear-powered aircraft program. I wish to comment further upon the military requirement for this program. Although the Air Force does not now forecast each specific configuration which future military weapons will eventually assume, we are certain that vital military applications will derive from the development of nuclear propulsion. I believe we are on the threshold of a new era in propulsion.

While it is too early to define the exact weapon system which may evolve, applications now foreseen emphasize the military development requirement for nuclear-powered aircraft.

Results of numerous studies have convinced me that for the foreseeable future a requirement will continue to exist for an advanced, operationally flexible, manned, intercontinental, recoverable, recallable,

strategic aerospace weapon system which can penetrate and attack the enemy's military forces. Surface-to-surface missiles are expected to increase in reliability, accuracy, and flexibility of employment to a point where they will represent a significant contribution to the overall strategic effort. However, there are certain fundamental capabilities which I consider mandatory as a part of our strategic posture and which are not characteristic of missiles. These dictate the retention of the manned weapon system as an integral part of our strategic force structure. Specifically we require the capability to search out, locate, discriminate, and attack targets of unknown or inexact location, we require the capability to exercise judgment when confronted with unforeseen situations; we require the capability of initiating corrective action in the event of malfunction; we require the residual capability represented by the recoverable and recallable features of the manned system; and we require the ability to return intelligence and damage assessment information.

Since the infancy of airpower, designers of long-range strategic weapon systems have been concerned with the problems of range and endurance. Although the jet engine has made possible the use of high speed and altitude, lack of optimum range and endurance has limited the flexibility of the manned strategic weapon system. Such limitations have restricted the routes of approach which can be used to attack the enemy allowing him some leeway in the quantity and location of his active air defenses. For example, with our current strategic capabilities, the enemy may expect the weight of an attack to be from the north and west, and concentrate his defenses accordingly. Since the fuel consumption of the jet engine increases with decreasing altitude, these limitations are especially pronounced in low-level tactics which are so costly and difficult for the enemy to counter.

Significant progress has been made toward overcoming these operational restrictions. However, we have been unable to design a strategic weapon system which meets fully our range and endurance requirements in the global sense. Development is proceeding in the use of chemical fuels which will certainly enhance our capability, but this will not completely satisfy our needs. Inflight refueling is a refined, dependable technique; nevertheless, it introduces many operational problems which could be substantially reduced by the employment of a global vehicle which does not depend on it.

The shortened warning time which we must expect in the future will increase the need for rapid reaction and mobility in our strategic weapon systems. Increasing the mobility of our strategic force is a means of complicating the enemy's targeting problem. It is also a means of giving relative invulnerability to our strike forces. An airborne alert may be an effective means of attaining these objectives. The employment of vehicles with global range and increased endurance will simplify the problem of airborne alert and make possible an all-directional, multilevel attack without inflight refueling.

Nuclear power shows promise of providing manned aerospace vehicles with global range and endurance characteristics. A nuclear-powered aircraft inherently will have a large payload capacity which offers several advantages. Many combinations of weapons and military subsystems can be carried, permitting great flexibility in handling various missions. This flexibility would be particularly useful in

limited war situations. Another important advantage of the very large payload is its probable effect of extending the inventory life of the system. Although technological advances in military subsystems will occur during the life of the vehicle, its payload capacity will favor the addition of new subsystems.

One of the initial embodiments of this concept which the Air Force has analyzed in some detail is the CAMAL system with which I am sure you are already familiar. Although the technical feasibility of achieving this capability looks promising, the Air Force realizes that there are many problems relating to operational practicability. These include such matters as ground support, operating techniques and procedures, cost effectiveness, basing, and hazards. Obviously, the Air Force does not wish to prematurely commit large sums of money for weapon system development and procurement without first determining (1) how such problems can be resolved practicably and (2) to what extent the weapon system program would result in an effective force for reasonable cost. Only through a flight development phase will pertinent information and data be obtained in these areas so that logical decisions concerning possible follow-on weapon systems can be made. This, in addition to propulsion system development testing, is the primary purpose of the flight test program. Only after the Air Force has achieved enough experience and accumulated sufficient data on resource requirements would weapon system development be contemplated.

In summary, there is a development requirement for nuclear-powered aircraft. Achieving our current technological position in the nuclear propulsion art has not been an easy task. This accomplishment has resulted from the concentrated effort of many highly competent technical people over a number of years. During this time we have experienced both disappointments and successes. It is my belief that the disappointments have been symptomatic of the magnitude of the problem and not of any deficiency associated with the technical people involved in the program. We are on the threshold of achieving technical success and should not compromise our development approach in any manner that would lessen our chances of early achievement of an effective military capability.

Representative Price. Thank you very much, General White.

Do the Joint Chiefs of Staff believe it to be militarily desirable to undertake a flight test program in extension of the present ANP program as soon as such a flight program is considered to be technically feasible?

General White. I believe that is a fair statement of their view. On the other hand, I don't think I am authorized to speak for the Joint Chiefs of Staff. That roughly corresponds to my own view at least.

Representative Price. Is that not also corresponding to an expression of the Joint Chiefs of Staff in recent consideration of the ANP program?

General White. Mr. Chairman, I think that is one you must call on the Secretary of Defense and the Chairman of the Joint Chiefs of Staff to answer, because I do not think any one individual has the authority to make a statement on behalf of his colleagues. We act as a body.

Representative Price. At least this is your view.

General WHITE. This is a generalization of my personal view in the matter.

Representative PRICE. I remember that when you appeared before the Senate Preparedness Subcommittee earlier in the year one of the reservations that you expressed personally to the Defense budget had to do with the ANP program. Would you elaborate on your position at that time?

General WHITE. I have long felt that the whole field of flight, both in the atmosphere and in space, will be greatly influenced by nuclear propulsion. I personally feel that we should get on with this just as fast as the state of the art permits. While I have been somewhat more optimistic about the rate at which we can progress in this field, I am forced to defer my official recommendations to the scientific advice that I receive. I can only say that I visualize that atomic power is a relatively new form of energy which has application in a most significant way to flight.

Representative PRICE. I recall that after you expressed this reservation I made a statement which was published in the press, and I said this:

> It is clear that General White and his expert military advisers in the Air Force believe strongly that the aircraft nuclear propulsion program (ANP) is important to the Nation's security interests and that the program is sufficiently advanced technically to warrant the commencement of work on an air frame and propulsion system suitable for first flight.

Was I reading your reservations correctly at that time?

General WHITE. As a layman, that certainly is a fact. But as Chief of Staff of the Air Force my official recommendations to my Secretary must take account of competent scientific advice. Unfortunately, I cannot claim to be a scientist or an engineer, and while I feel that my imagination tells me that this has an enormous application, we certainly can only move at a rate which is technically feasible, and that rate, as far as I am concerned, is determined by competent scientific personnel which exist both in the Air Force and in the Secretary of Defense Office, as well as other places.

Representative PRICE. Let me ask you a personal question, then. Do you feel it is being determined now on the basis of technical competence or whether or not there is some budgetary restriction involved?

General WHITE. I feel that we are proceeding almost entirely on what the scientists tell us is the true state of the art. I can't say that budgetary implications are not involved because if we had unlimited funds I have no doubt we would take more chances than we are presently willing to take in the light of the scientific advice we get.

Representative PRICE. I respect your judgment as a military man, and also your loyalty to your position on the team on which you serve. Basing it strictly on a technical problem, then, I think I must be compelled to read into the record at this point the recommendations of the General Advisory Committee of the Atomic Energy Commission, the recommendations having been made in June of this year, less than a month ago. They said that—

> work by General Electric has now reached the point where it appears likely that fuel elements can be developed which will be capable of making the performance of the direct cycle reactor high enough to be useful for propulsion of military aircraft. If the Department of Defense is in favor of proceeding with this

system, then the Reactor Subcommittee recommends that the necessary steps be taken to develop the XMA powerplants by General Electric and that these steps include provision for flight testing and demonstration of these propulsion systems as proposed by General Electric and Convair.

That would seem to me to resolve the technical aspects of this to the point where if we were determined to put the effort into it we could accomplish early flight within a reasonable time.

Mr. Secretary, would you like to comment on that?

Mr. TAYLOR. Of course, the technical feasibility of flight is not questioned. We all agree that it is technically feasible to fly with an atomic powerplant. I think what we are talking about is how good a powerplant and how good an airplane are we likely to develop within the time limit.

Representative PRICE. I would not necessarily agree that is what we are talking about. We are talking about the earliest possible flight from which improvements can be made to determine how good nuclear propulsion will be in the future.

Mr. TAYLOR. But there is a limit to how well we can project the system at this point. In other words, we have pretty good capability of knowing how far we are going to get with this type of reactor. We have a pretty good idea of how good this airplane will be if the development works the way we think it might work.

Representative PRICE. I think you are going beyond the concept of what we hope to learn from the early flight. I think it was adequately explained in General Keirn's fine statement.

He enumerated the many things that we will learn from the early flight and that would be difficult to learn or to improve upon until we do have a plane in the air.

Mr. TAYLOR. I am sure that we will learn the things that General Keirn mentioned and that I mentioned. I do not expect that flight testing will be the means of a breakthrough into a performance regime which is far above what we can anticipate at this point. In other words, the ceiling of our efforts can be to some extent anticipated. Perhaps we are trying, as a military vehicle, to evaluate the plane at its ceiling against other military systems. There is a sensible importance to assign to the early flight before we have reached the point where we can see our way to the end.

Representative PRICE. Of course you are getting back into the controversial determination of the word "usefulness." As I stated in the opening of the hearing this morning, I have had a feeling for a long time that considerable confusion has developed from the use of this word. I think it is time that we nail down the facts as regards the possibility of an early flight and just determine what we mean by usefulness and then get on with the job. I think that is the purpose of this hearing.

Mr. TAYLOR. I would think you could evaluate usefulness as being competitively valuable as against other military systems.

Representative PRICE. That may be true. I think appropriate treatment of this word was given in General Keirn's own statement. He is the director of the project. I think he contributed a great deal of useful information on which the committee might make a determination and on which the Defense Department should ultimately make a determination regarding what we mean by usefulness.

Mr. TAYLOR. Again General Keirn and I agree on what you mean by flight testing.

Chairman ANDERSON. Except that you are not quite ready to learn it. Is that the difference?

Mr. TAYLOR. I would like to look beyond the points which we will learn by flight testing to the vehicle which becomes a militarily acceptable vehicle in competition with other systems.

Chairman ANDERSON. Militarily acceptable in competition with other articles.

Mr. TAYLOR. Other systems.

Chairman ANDERSON. "Usefulness which would make it competitively valuable." Do you always wait for that? That is the whole problem in this thing, as to whether you are going to have flight testing to try to learn something, or are you going to wait until these materials which have already been developed are developed to some finer state. Surely in the discharge of your duties, if you are considering nuclear flight, you should look at what happened in the development of a nuclear submarine. We had testimony the other day from a man who helped build the *Nautilus* that it is already obsolete. I think anybody who ever took the controls of the *Skipjack* and tried to compare it with the *Nautilus* would recognize the *Nautilus* is a hopeless ship.

Did we make a mistake in building the *Nautilus?*

Mr. TAYLOR. No, sir. At the time we built the *Nautilus* there was no doubt but what it would be a very important contribution to the submarine field.

Chairman ANDERSON. I am happy to have you state that because the Joint Committee was not always assured that same way. There were three or four people who did not think it was a very wise idea to go ahead with the *Nautilus* because they did not know that it would work.

Mr. TAYLOR. We always knew that if the reactor and the nuclear development worked out to the proper point it would be a very successful submarine.

Chairman ANDERSON. But nobody knew what they would do with it. It was going to be some sort of pleasure voyage ship. Nobody had any concepts of it. Suddenly somebody comes up with a new use for it that makes it part of the weapons system. We did not always wait on the development.

Are you familiar with the fact that the *Seawolf* was built with a sodium device in it that finally did not work, and we had to take it out and throw away millions of dollars and put back in pressurized water and now it goes ahead pretty well. Those things happen, do they not, in the development of a program? It might be that the first nuclear-propelled airplane that was built would prove to be a little unwieldy in the sky. Somebody might throw away the direct-cycle reactor and go back to the indirect-cycle reactor, but right now the direct cycle looks pretty good, and a lot of people would like to see it built.

Mr. TAYLOR. When you evaluate either the direct cycle or the indirect cycle there are certain limits to the performance, and whether that performance is competitive with other systems I think is the thing that is worrying the Defense Department.

Chairman ANDERSON. I only go back to what Secretary Douglas said in June 1957. I quote you his words in a letter to the Joint Committee:

> We are convinced that early nuclear-powered flight testing is an important part of the program. It is believed that accomplishment of actual nuclear flight will crystallize and clarify many of the problems concerning radiation hazards, nuclear powerplant operation and maintenance, and the actual capabilities of nuclear-powered aircraft.

What has happened since June 1957 that would make anybody believe that is not a good statement today?

Mr. TAYLOR. I think he would make the same statement today.

Chairman ANDERSON. I am happy to hear that. General Keirn certainly met all their technical objections to trying early flight and yet it is not getting underway. We had a statement just a moment ago by you that I read as saying that we did not have to hurry so much, "We now feel it would be wiser to wait until better performance is demonstrated."

How are you going to demonstrate what you can't test? These are your words and not mine, Mr. Secretary.

Mr. TAYLOR. That is right.

Chairman ANDERSON. "We now feel it may be wiser to wait until better performance is demonstrated."

How are you going to demonstrate it when you cannot get it off the ground?

Mr. TAYLOR. It doesn't have to be demonstrated in the air.

Chairman ANDERSON. But you want to demonstrate it.

Mr. TAYLOR. I want to demonstrate it in the air to find all the corollary and related conditions for a nuclear airplane.

Mr. RAMEY. We had testimony from General Keirn that you do not even have a ground test slated now with a target date for operation, although the last time we had testimony you did have a ground test scheduled.

Mr. TAYLOR. He was speaking of a ground test in a wind tunnel, I think, which was a sort of substitute.

Chairman ANDERSON. General Keirn is shaking his head. You can look around. Of course he was not testifying to that.

Mr. TAYLOR. He says he was not.

Chairman ANDERSON. You retreated from the position you had reached. You got up to where there might be a ground test and there was such great fear it might demonstrate that this plane would fly that you have to abandon it. Now, why? What was the impelling motive?

Mr. TAYLOR. I think the impelling motive was simply to get a better performance out of reactors.

Chairman ANDERSON. How do you know what performance is going to be until you test it? How can you have something better when you don't have the first one and the second one? If you are only going to have one it is not better, is it?

Mr. TAYLOR. I think you are confusing, or maybe I am confusing, ground test and flight test.

Chairman ANDERSON. I may be. I wouldn't guarantee you I am not. General Keirn—I hope if I misquote him he will correct me—at one time thought, I believe, if we had a ground test it might help us along on our program toward a flight test and the flight test of one would

prove things that we could do with another, and another, until we finally had the materials that would do the job that is militarily important which General White has referred to. I do not think that General White would say that he has listed all the possibilities that may happen as a result of flight in a nuclear plane. But he sees some things in here that could be done. Reconnaissance, and so forth, that is very important to him and might be extremely important. Global range and endurance characteristics—these are things that he would like to know.

The scientists might tell you, "Let us not test them now because we might not find out anything about them." But it is important, in the opinion of General Keirn, who spent a good many years in this field, that if he could get a flight test he would learn something about all these characteristics, including shielding. I know you do not learn from experiences of other men, but Admiral Rickover has learned a lot about shielding in building several submarines. He has found out—I hope I am not misquoting him—I think he has found out that he overbuilt some of the shielding or overdesigned some of the shielding in his first submarine. Possibly people could find out that they put more shielding then they needed in an airplane. What is so wrong in doing what Secretary Douglas thought was desirable 2 years ago?

Mr. TAYLOR. I think it comes right back to a budget situation.

Chairman ANDERSON. That is what I thought. That is exactly what I thought. It comes right back to budget considerations.

Mr. TAYLOR. Secretary Douglas has told me——

Chairman ANDERSON. That is precisely what I wanted you to say but it took a long time to get it out. We know that is the trouble, budget consideration. These things that General Keirn was talking about cost money.

Mr. TAYLOR. They do.

Chairman ANDERSON. Yes. Yet we have had some testimony about a lot of things that cost money that did not work out so well. We didn't worry about those. In an overall effort a few million dollars for this flight test is not too tragic.

Mr. TAYLOR. As Secretary Douglas has told me, he thinks this program would come before any additions to the manned aircraft program. In other words, it would come between missiles and manned aircraft. That would be his view.

Chairman ANDERSON. Has the Air Force recommended to the Defense Department the utilization of additional Air Force funds to achieve a ground test and flying capability in connection with nuclear-powered planes?

Mr. TAYLOR. Would you say that again?

Chairman ANDERSON. I will try to keep from confusing you. You made the original recommendation running into well over $100 million for this sort of work and then you stopped it and reversed yourself. So the question is, Has the Air Force recommended to the Defense Department the utilization of additional Air Force funds to achieve a ground test and flying capability in connection with a nuclear-powered plane?

General WHITE. I have asked General Keirn. He says such a recommendation has been made. The action he does not know and I do not know. There was some millions of dollars recommended.

Chairman ANDERSON. It was made. I better not comment on what happened to it. I think it was decided to let it alone for a while. I know the recommendation was made. That is one of the reasons why some of us have felt that General Keirn——

General WHITE. We would be glad to supply the answer but I personally do not know what happened to it.

(The information referred to follows:)

On October 1, 1958, the Air Force submitted the fiscal year 1960 budget program to DOD. Included therein was $101.5 million Air Force funds for ANP with an additional $45.2 million requested from the DOD. The total $146.7 million was to support an expanded ANP development program leading to nuclear flight testing. The $101.5 million was to support the expansion of the propulsion effort to include flight qualification of the direct cycle XMA powerplant. The $45.2 million was to support initiation of the development and fabrication of two experimental flight test airplanes and the initiation of a reactor test facility at the P and W-operated Connecticut Aircraft Nuclear Engineering Laboratory (Canel) facility.

After DOD review between October 1, 1958, and November 27, 1958, the program expansion to include flight testing was disapproved and the program objectives were restricted to reactor development with enough turbo-machinery and other support work consistent with such objectives. The funding level for the Air Force in fiscal year 1960 compatible with this objective was established at $75 million.

Chairman ANDERSON. I regret to say that the House is on a long quorum call and the House Members are not expected back. I do not desire to go on by myself. Admiral Hayward, could we have you at 2 o'clock this afternoon?

Mr. TAYLOR. Yes, sir.

Chairman ANDERSON. This will be in the old Supreme Court room.

Admiral HAYWARD. Yes, sir.

Chairman ANDERSON. Admiral, your patience is commended on all sides. We have had you before us several times, and we always appreciate you. I would like to have your testimony before the full committee.

We, therefore, will be in adjournment until 2 o'clock in the old Supreme Court room in the Capitol Building.

General White, could you and the Secretary be available for a while in case other members desire to ask questions? We will try to release you very, very early, but there might be some questions.

(Whereupon, at 12:35 p.m., the committee was recessed, to reconvene at 2 p.m. the same day in the old Supreme Court room, the Capitol.)

AFTERNOON SESSION

Representative PRICE. The committee will be in order.

When the morning's session concluded, Senator Anderson had concluded his questioning of General White and Secretary Taylor. However, if there are any other questions to be propounded to the Air Force, we will call those two witnesses back, or at least Mr. Taylor, since I do not see General White here.

Are there any questions to be directed to the Air Force by any member of the committee?

If not, the committee will proceed to the next witness, who will be Mr. Fred A. Bantz, Under Secretary of the Navy.

I understand you are going to be accompanied by Admiral Hayward.

You may proceed.

STATEMENT OF HON. FRED A. BANTZ, UNDER SECRETARY OF THE NAVY; ACCOMPANIED BY VICE ADM. JOHN T. HAYWARD, DEPUTY CHIEF OF NAVAL OPERATIONS FOR DEVELOPMENT

Mr. BANTZ. Mr. Chairman and members, we have a new research man who is Assistant Secretary of the Navy for Research and Development. He has only been aboard for 10 days and has not had a chance to familiarize himself with the program, and that is why I am appearing.

The Navy position on aircraft nuclear propulsion (ANP) is now quite clear, and I welcome this opportunity to summarize it for you.

The Navy needs aircraft of extremely long range and endurance, and we believe ANP has an excellent potential for this purpose. We do, however, recognize the serious technical and funding problems to be solved before this potential can be exploited in a weapons system.

Navy studies indicate current state-of-the-art in ANP will support development of a nuclear propulsion system suitable for test purposes and we have recently awarded a contract to Pratt & Whitney Division of the United Aircraft Corp. to initiate development of components required in transferring nuclear heat from an intermediate heat exchanger to an aircraft engine. This contract is intended to support future development of a complete nuclear propulsion system suitable for ground and flight test and evaluation.

Development of propulsion system components is expected to continue through fiscal years 1960 and 1961. In 1962 ground test of a single aircraft engine system on chemical heat is planned. The time schedule and planning for further tests with heat from a nuclear reactor have not been established. Results of ground and flight test phases to be conducted will provide the basis for decisions on the direction and extent in which an operational nuclear-powered aircraft can be pursued. An operational ANP system for the Navy could include the use of large long-range and endurance seaplanes designed to perform a wide range of naval missions. In order to reduce radiation problems and permit maximum aircraft utilization, early Navy nuclear-powered seaplanes will probably utilize heavily shielded reactors of relatively low power and long operational life.

It is believed that as the technology of aircraft nuclear propulsion grows in step with other technological developments in the future, the variety of operational demands for a nuclear-powered seaplane system will become manifest.

That is the end of the statement, Mr. Chairman. I said Admiral Hayward will be here shortly, and meanwhile if there are any questions other than the real technical side, I will attempt to answer them.

Representative PRICE. Mr. Secretary, has the Navy established a firm requirement for a nuclear-powered aircraft?

Mr. BANTZ. I don't think you could say we have established a firm requirement for one. I think what the Navy is attempting to do now is to develop first a prototype of an engine to see what it could expect to develop in the plane. I think to some degree we might compare it with the Navy's development of a nuclear-propelled submarine.

In other words, the Navy built a nuclear powerplant for the original nuclear submarine which is the *Nautilus*. That was a land prototype and it was well along before the submarine itself was started.

The reason for that was to see just what changes, as a result of this land-test vehicle, would be necessary in boats. I would think that probably the same would apply as far as a nuclear-propelled engine for an airplane is concerned.

Representative PRICE. Perhaps the use of the term "firm requirement" would stretch it a little far, particularly at this stage of the art. Would you say that the Navy has a requirement for a nuclear-powered aircraft?

Mr. BANTZ. I would like to answer that, Mr. Chairman, by saying that if an engine that is practical for a plane that has reasonable assurance of longevity in the air, and by that I mean number of days, and safety of the crew and sufficient to carry a payload that is worthwhile, then I would say that there would be such a requirement. I think they are a long way from the development of an engine that would meet such a requirement.

Representative PRICE. Within the Navy there has been some study made, at least, or has there been a study made that would indicate the various missions of military importance that could be performed by such an aircraft?

Mr. BANTZ. I think if there were a plane such as I just described, if that were a practical one to build in the days of advancement of technology, it could serve a very worthwhile purpose.

Representative PRICE. Does the Navy have clear guidance from the Department of Defense as to future objectives for a Navy program?

Mr. BANTZ. When you say "firm guidance," I don't know that we have any specific outline from the Department of Defense. To my knowledge, the Joint Chiefs of Staff have never come up with a definite military requirement for it. If they have, I do not know of it.

Representative Price. What is the Navy's present budget for the nuclear-powered program?

Mr. BANTZ. By "present," what do you mean?

Representative PRICE. Fiscal 1960.

Mr. BANTZ. In fiscal 1960 with our reprograming we should have about $6½ million, as I recall.

Representative PRICE. This would be more or less in research?

Mr. BANTZ. It is for the contract. We have recently awarded a contract to Pratt & Whitney for the development of components which we hope will eventually lead to the development of an indirect cycle engine.

Representative PRICE. Does this reflect the Navy's opinion as to the importance of the program? Would you think that the Navy might feel that the program was of greater importance to the point where you would like to reprogram your activity in this connection?

Mr. BANTZ. I think part of that would depend on the developments of the direct cycle of the Air Force engine. Part of it will depend on the development as a result of our recent contract with Pratt & Whitney.

Representative PRICE. Is there any disposition on the part of the Navy to seek an acceleration of their end of the program?

Mr. BANTZ. No; I don't think I could say that. I think that the Navy is adopting a very similar program to what it did originally

on the nuclear-powered submarine. As I say, there, the land prototype was the first step in it and we are in the hopes that this will be the first step to a land prototype of a reactor that will be something comparable to what we hope to put in the plane eventually.

Representative PRICE. Mr. Hosmer.

Representative HOSMER. Mr. Bantz, General White was not able to forecast a future configuration for ANP. Secretary Taylor said the Air Force was not clear as to the exact military use. I take it from your testimony that the Navy has in fact developed a specific use for ANP.

Mr. BANTZ. I don't think I said quite that, Mr. Hosmer. What I tried to say was that if, after reasonable development work on the indirect-cycle engine, we saw some potential for it, then we could see some use for it in antisubmarine warfare.

Representative HOSMER. You can see some use for it now in antisubmarine warfare, can you not?

Mr. BANTZ. If we can develop a plane that is of the type that I attempted to describe.

Representative HOSMER. In other words, at this point you have a use to which it could be devoted?

Mr. BANTZ. Yes.

Representative HOSMER. ASW is antisubmarine warfare.

Mr. BANTZ. Yes, sir.

Representative HOSMER. That involves aerial patrols of the oceans in which enemy submarines are liable to proceed to attack either this coast or the free world shipping; is that right?

Mr. BANTZ. Yes, sir.

Representative HOSMER. ASW is a large scale operation during a war and I suppose during a cold war, too.

Mr. BANTZ. Yes, sir.

Representative HOSMER. The ANP propulsion for patrol aircraft, I take it, would enable those craft to stay on stage longer, range farther and make a more complete search for the undersea vessel. Is that it?

Mr. BANTZ. If it could not, there would be no sense in trying to develop one, sir.

Representative HOSMER. I asked you about this rather specifically because I take it for the first time on the record we have a specific use that is understandable and does not seem to be overlapping with some other type of weapons system. You indicated that you are spending about $6½ million on this development.

Mr. BANTZ. That is the program for 1960 which has not been approved as yet by the Congress. Part of that is reprograming. Actually there was only $2 million in the direct appropriation. The balance would be as a result of reprograming.

Representative HOSMER. That represents on the Navy's part a considered evaluation of the priority of this particular program in relation to other programs that the Navy is carrying on, is that correct?

Mr. BANTZ. I would say this, Mr. Hosmer: As far as the Navy is concerned, in this indirect-cycle type of engine we are a long way from what we could expect to accomplish for the purpose that we would build an indirect-cycle engine with nuclear power.

In other words, what I am trying to say is it will be quite some time before we know whether or not we can put a lot more of our efforts and money into it.

Representative HOSMER. As a matter of fact, for the defense of the country there are other pieces of hardware that you need to buy before you buy this, is that right?

Mr. BANTZ. There are other proven pieces of hardware that we are buying in quantity and improving on right along, yes, sir.

Representative HOSMER. There are not things that you would take money away from in your plan for the next year and put on this program?

Mr. BANTZ. That is right. Based on the present state of the art of the so-called indirect-cycle engine.

Representative HOSMER. Are you satisfied that in the best judgment of yourself and those who advise you in the Navy, that this is in the best interests of the United States of America and its defense.

Mr. BANTZ. I think that is a reasonable statement, yes, sir.

Representative HOSMER. Thank you.

Representative PRICE. You mean the best interests immediately. But are you not losing sight of what the future might hold?

Mr. BANTZ. No, Mr. Price. What I am trying to say here is that until we have a little more knowledge of what this indirect-cycle engine will really do.

Representative PRICE. I am not raising the issue between indirect cycle and direct cycle.

Mr. BANTZ. I mentioned that.

Representative PRICE. I see no opposition to any one exploring the various avenues of approach. When you talk about putting what money you have into hardware that is available, that hardware would not be available today if you had not taken some research and initial steps some time ago.

Mr. BANTZ. That is right.

Representative PRICE. So you get down to the question of whether or not you invest to the fullest possible extent in research and development of any new concept.

Mr. BANTZ. That is right. We are developing many different weapons systems at the present time. Some of them are in a much more forward stage than another as far as development is concerned.

Representative PRICE. You would not say 5 years ago that you would not put any money into the ICBM program because you had other types of weapons available at the time?

Mr. BANTZ. I don't think I have said that, sir. I said we are putting a reasonable amount of money into it. It is small until we know a little bit more about what is practical to accomplish. Admiral Hayward is here now and if there are any technical questions he would be in a much better position to answer as far as the state of the art of this engine is concerned than I would be.

Representative PRICE. Mr. Van Zandt, have you any questions?

Representatives VAN ZANDT. Is Admiral Hayward going to make a statement?

Admiral HAYWARD. I have no statement.

Representative VAN ZANDT. Admiral Hayward, how long have you been with this program?

Admiral HAYWARD. I went with the Manhattan district in 1944, sir.

Representative VAN ZANDT. You are familiar with the ANP program from that time until this?

Admiral HAYWARD. Yes, sir. Very familiar with it.

Representative VAN ZANDT. My colleague from California in questioning the Secretary developed the facts that the Navy does have a need for a long-range ANP aircraft. Would you concur in that statement?

Admiral HAYWARD. Yes, sir; I would concur in it, that we have a relatively low power subsonic aircraft requirement.

Representative VAN ZANDT. What is it, ASW?

Admiral HAYWARD. And early warning.

It has great military potential but I would not spell out a system for it yet.

Representative VAN ZANDT. Years ago in the consideration of the ANP program and its application to ASW and early warning, and so forth, the Navy's thinking was to apply it to a flying boat.

Admiral HAYWARD. Yes. Obviously it was a safer device for us. You had greater cubic capacity for what we wanted to do.

Representative VAN ZANDT. Do you think had we at that time financed the Navy effort that we might be further along than we are today?

Admiral HAYWARD. As I have said before, this particular program is a pretty good monument of how not to run a technical program. The first objective should have been to fly an airplane whether it went at 50 knots or 100 knots. Getting back to our particular program in the Navy, this was Admiral Rickover's philosophy. As you remember, I am sure, he made the statement that if the *Nautilus* was to fail it was to fail for only one reason alone, and that was the nuclear-propulsion plant. He didn't attempt to get the submarine to end all submarines to do this. We wanted a nuclear-propulsion plant. Of course, the gains from a nuclear-propulsion plant in a submarine have made a true submersible. This was quite clear. Of course, the nuclear-propulsion plant for an airplane would give it this tremendous range and endurance. This is a good example of what we have done in our country in the way of spelling out a system and then trying to invent on schedule and we have not invented on schedule.

Representative VAN ZANDT. In other words, you think we made the wrong approach?

Admiral HAYWARD. Originally, yes, sir, I do.

Representative VAN ZANDT. The Navy has an opportunity now to acquire a flying boat from the British. Do you think we have gone too far now to apply your thinking outlined a moment ago?

Admiral HAYWARD. Let me make it quite clear, Mr. Van Zandt: I agree with Dr. York's decision. Dr. York's decision is right technically. It is just too bad this was not done a long time ago. As far as the flying boat program is concerned, we proposed that to the Department of Defense as a national program. I don't feel as far as being in the R. & D. business in the Navy that I would go and spend all my money on this just for the Navy's application. No, I wouldn't.

Representative VAN ZANDT. In other words, Dr. York's position, which you support, is to produce the nuclear powerhouse and perfect it, and then install it in aircraft construction for that purpose.

Admiral HAYWARD. Yes, sir. We have tried in the past to try to bring an engine and airplane out at the same time. Congress has criticized us, and rightly so. You may recall the barges taking the airplanes down the river with the engines. We have never been able to do this. The first thing you have to do is to get an engine. We don't have an engine.

Representative VAN ZANDT. That is all, Mr. Chairman.

Representative PRICE. Senator Jackson.

Senator JACKSON. I just have one or two questions.

Has any consideration been given to the possibility of utilizing dirigibles or blimps as the vehicle in this type of operation? I realize that the engine is the fundamental thing, obviously.

Admiral HAYWARD. No. Industry itself has looked at this, Senator, but from the Navy's point of view we have not given serious consideration to this at all.

Senator JACKSON. In your judgment, I take it, the important consideration is to get a plant.

Admiral HAYWARD. That is correct.

Senator JACKSON. A nuclear plant, that is. Then the application will follow on from there.

Admiral HAYWARD. That is correct, sir.

Senator JACKSON. From the standpoint of early operation, would a seaplane be more advantageous than a landplane from the standpoint of safety?

Admiral HAYWARD. As an aviator I would answer this personally. A seaplane has a tremendous advantage in that you have tremendous runways. There is no such thing as an aborted takeoff. So you can run for miles when you have marginal takeoff power. I think it has tremendous advantage from the safety point of view than over-the-land planes. There are planes on an island that you could build a runway and use a landplane. A seaplane is inherently safer, I feel, for this type of operation.

Senator JACKSON. Especially in the early stages of development?

Admiral HAYWARD. Yes, sir; I feel this very strongly.

Senator JACKSON. The Navy has a very substantial requirement, assuming that such a system is feasible, even though it is subsonic.

Admiral HAYWARD. Yes. Our requirement is primarily subsonic, definitely. We would not have any supersonic requirement. We could take a turbo-prop chemical engine and use it. This is where our requirement differs from the Air Force. We don't want a supersonic nuclear propulsion.

Senator JACKSON. At least not with the existing systems that you have.

Admiral HAYWARD. No, sir; not what we are thinking of.

Representative PRICE. Mr. Westland.

Representative WESTLAND. Admiral, we always seem to be in a race with Russia with so many things. I guess this nuclear propulsion is one of them. Certainly in some fields we are ahead and perhaps in some fields we are behind. In your consideration of this problem have you given any value to the psychological point of view in the world of being the first to launch a nuclear-powered aircraft?

Admiral HAYWARD. In answer to that question, primarily my decision is based on technical, not psychological reasoning. If I thought

there was great military import to the fact that they got it first, I might feel stronger. I do not really think that there is tremendous military import to the fact that they are first on it.

Representative WESTLAND. I recall when they sent up their sputnik that many people said there was no military value to this thing going in orbit and so forth. Nevertheless, the Congress rushed around hither and yon and appropriated funds in great quantities for a crash program. I do not want to be saying those same things again. If the Russians launched a nuclear-powered aircraft, do you think we will be put in that sort of position?

Admiral HAYWARD. Of course, at this particular point if they have it they are going to beat you anyway. I think maybe the best thing to do—no; I don't think it has the same import. In looking at the challenge, that the Soviet throws at us in the space business, they could see what we were doing and they can see today what we are doing. I don't feel it has the same psychological impact at all. The reactor is nothing but a heat source. It does have a tremendous range and endurance but I don't feel it would be the same psychological victory that the sputnik was. I am no psychological expert. I speak strictly from the technical point of view.

Representative WESTLAND. I understand that. You heard me ask General Keirn earlier this morning whether or not an aircraft of a lesser military value could be flown sooner, and I would like to ask you the same question, Admiral.

Admiral HAYWARD. Yes, sir. An airplane of a lesser military value could be flown. That was the Princess program which we proposed. This was strictly a test bed. It was strictly the three seaplanes which the British have and for the cost of $220 million, as I recall the dates and the figures, we could have flown it in 1962 or 1963, let us say. This was strictly a test bed. It was prepared to do this, and it was proposed as a national program to the Secretary of Defense at the instance of the committee a year ago after they asked us to look at this problem and the Secretary of Defense turned it down, and he was correct in turning it down.

Representative WESTLAND. It would be correct to say that you could have flown a nuclear-powered aircraft by 1962. Is that a true statement?

Admiral HAYWARD. 1963, I would say. That was made last fall. Now this is no longer true.

Representative WESTLAND. I understand that. Had the situation been the reverse, you could have had a nuclear-powered aircraft flying by 1963?

Admiral HAYWARD. You could have had a test bed of this type; yes, sir.

Representative VAN ZANDT. Admiral, is it not true the Navy's first thinking for an ANP program involved the fireball homogeneous type reactor?

Admiral HAYWARD. Yes; that is essentially correct.

Representative VAN ZANDT. When the physicists ran into difficulty with this type of reactor, the Navy discarded it.

Admiral HAYWARD. That is right.

Representative VAN ZANDT. Then the Navy moved into the indirect cycle of Pratt & Whitney?

Admiral HAYWARD. Yes, sir.

Representative VAN ZANDT. That really has stretched the time factor, has it not, for the Navy?

Admiral HAYWARD. That is true. Our requirements were different than the Air Force requirements.

Representative VAN ZANDT. Admiral, how much money has the Navy to date in nuclear-powered submarines, starting with research and development and leading up to the *Nautilus* and those submarines operational today?

Admiral HAYWARD. It is roughly between $800 and $850 million. That covers the R. & D. cost. The committee has these figures, I am sure.

Representative PRICE. We have the figures.

Admiral HAYWARD. Plus the operating submarines we got out of that.

Representative VAN ZANDT. That includes the R. & D. and the operational submarines of today.

Admiral HAYWARD. Up to that time, yes, sir. Of course, the philosophy that Admiral Rickover pursued was entirely different than the philosophy pursued in ANP.

Representative VAN ZANDT. That is true. I was just looking at this figure which includes the money for fiscal 1960, for ANP. The total is $990,600,000. All we have today is an indirect and direct cycle reactor plus a lot of facilities, whereas in the submarine field we have about a half dozen operational nuclear-powered submarines. In other words, we have a complete weapons system.

Admiral HAYWARD. That is correct.

Representative PRICE. If the gentleman will yield, I don't think it is quite fair to say that is all we have. We have considerably more knowledge of this program than we had before.

Admiral HAYWARD. Yes, sir.

Representative PRICE. A high percentage of this money has gone into the most valuable type of work which is of benefit to all reactor programs.

Admiral HAYWARD. That is right.

Representative VAN ZANDT. That is true.

Admiral HAYWARD. There are an awful lot of things which we got from this program from an aircraft point of view.

Representative PRICE. A great deal of basic knowledge has come out of this program.

Admiral HAYWARD. Yes, sir. I would not make any statement that would reflect on the people who worked on that program because they have not had the same results as Admiral Rickover.

Representative VAN ZANDT. We have learned a lot about high temperatures and developing the necessary metals that will take these high temperatures. That is true. My question went primarily to the weapons system. In the submarines we have one and in the ANP program we do not have one.

That is all, Mr. Chairman.

Representative PRICE. Mr. Hosmer.

Representative HOSMER. I would like to ask the Admiral as an aviator and in relation to strategic aircraft that come in but drop

the attack because they are destroyed or damaged, defending against them is a matter of interception and destruction. Is that correct?

Admiral HAYWARD. Yes, sir.

Representative HOSMER. In the subsonic attack airplane propelled by a nuclear reactor, is there any break as far as destroying them goes from the defense standpoint? Is it the same or is it more difficult?

Admiral HAYWARD. Strictly as an opinion I would say it is roughly in the same category. An airplane is an airplane whether it is nuclear propelled or not. The nuclear propulsion has the range and endurance but it is no different from another airplane from the interception point of view.

Representative HOSMER. It has no advantage from the standpoint of penetrating and accomplishing the mission?

Admiral HAYWARD. Not from the penetration side. Of course, it has the advantage of being airborne for a considerable period of time.

Representative HOSMER. That is all.

Representative PRICE. Thank you very much, Mr. Secretary, and Admiral Hayward.

Mr. BANTZ. Thank you, gentlemen.

Representative PRICE. The next witness will be the Honorable John A. McCone, Chairman of the Atomic Energy Commission.

We are glad to have you before the committee again.

STATEMENT OF JOHN A. McCONE, CHAIRMAN, ATOMIC ENERGY COMMISSION; ACCOMPANIED BY MAJ. GEN. D. J. KEIRN, USAF, CHIEF, AIRCRAFT NUCLEAR PROPULSION, DEPARTMENT OF DEFENSE; AND CHARLES L. MARSHALL, DIRECTOR, DIVISION OF CLASSIFICATION, ATOMIC ENERGY COMMISSION

Mr. McCONE. Thank you very much.

I have a brief statement, Mr. Chairman, which I will read, if you so permit.

Representative PRICE. You may proceed in your own manner.

Mr. McCONE. Mr. Chairman and gentlemen, I appreciate the opportunity to make this statement in your hearings on the ANP program in which I have taken considerable personal interest. My interest dates back to 1947 when I was a member of the Finletter Commission.

Later on, back to 1950 when as Under Secretary of the Air Force we saw in nuclear propulsion a means of eliminating the plauging range restrictions of our chemical aircraft. Currently, of course, I view the program not only from its contribution to the aeronautical sciences, but also in relation to its broader contributions to the general state of nuclear technology.

Representative VAN ZANDT. Mr. McCone, would you take a few minutes and give us a little background information of the early thinking of this ANP program, back when you were on that Board appointed by Mr. Finletter, and again as Under Secretary of the Air Force.

Mr. McCONE. In 1947 the Air Policy Commission went into this matter in some considerable detail. You will recall this was being carried on under the name of the NEPA project at that particular time.

There were a great many people who were very ardent protagonists of the program. We were impressed, as I recall, by the fact that those who were actively promoting the idea could see the advantages of a nuclear-powered aircraft. They could see what could be done with an aircraft of unlimited range, and so forth.

In those days we were not thinking in terms of supersonic planes. They were inclined to rather brush aside the hard technical problems of developing the reactor and the shielding and the airplane itself. Therefore, as I recall, in our recommendations we suggested that this matter be given careful study, and be a joint program of the Air Force and the Atomic Energy Commission and the Navy and the NACA, and that priority be given to solving the technical problems as rapidly as possible.

In 1950 and 1951, as Under Secretary of the Air Force, I reviewed this project a number of times. This was 3 years later. In the intervening years very little progress has been made, except that there were some new visions as to how it might be used and the advantages of the plane, if we had it, but no substantive steps have been taken toward solving the problems of which I speak.

Therefore, the Air Force took actions at that time, jointly with the Atomic Energy Commission and the NACA, to initiate programs. At that time, for instance, General Electric was brought into the program. Those were my early relations with the nuclear-propelled aircraft.

Representative VAN ZANDT. Thank you.

Mr. McCONE. The task of developing an aircraft nuclear propulsion system is not any easy one. We recognized this fact when the project was first begun. As a matter of fact, it was considered one of the most difficult scientific and engineering tasks that we had ever undertaken. Our scientific advisers, the Lexington group, told us in 1948 that it might take 15 years or more and something well over a billion dollars before we would achieve success.

The Lexington group, as a matter of record, was a group employed under contract by the Atomic Energy Commission, and I believe the Air Force, jointly, at Massachusetts Institute of Technology, and they assembled scientists and specialists and spent several months in the summer of 1948 making a study.

The promise afforded by success, however, was considered so far reaching as to be well worth the investment.

Now, some 11 years later, I still consider that the decision to conduct a vigorous research and development program for achievement of this objective was a wise one. Progress, while it has appeared slow in the eyes of the enthusiast, has been positive and continuous.

Here I might say that sometimes the wish for progress, the vision as to the advantages and an apparent willingness on the part of some visionary people to ignore the hard technical problems involved, and the steps that must be taken for their solution, has caused some to feel that progress has been very slow, yet in many areas it has been quite remarkable.

Technology has been substantially advanced in such areas as characteristics and behavior of materials at high temperatures, reactor physics, shielding, and radiation resistant materials. Our fundamental technology has now been brought to the point that the ques-

tion is no longer "can we fly on nuclear power," but rather "in what manner do we wish to fly on nuclear power, when, and with what kind of performance?"

Even so, there are two fundamental considerations with which I am sure we are all familiar, but of which we unfortunately often lose sight. First, we must keep in mind the extreme complexity and magnitude of the task of achieving a useful aircraft powerplant. Consider the fact that to go from our present land and naval reactor technology to useful aircraft applications requires an improvement factor of manyfold in the combined areas of size and weight reductions and power extraction. For example:

(*a*) Coolant temperatures in operating power reactors constructed to date are in the area of 500° to 850° F. while aircraft reactors must employ temperatures at two or three times this in order to be reasonably efficient. Turbine inlet temperatures for conventional jet engines are in the area of 1,600° to 1,800° F.

That is a comparison of 500° to 850° versus 1,600° to 1,800° and is just a fair measure of how difficult a problem we face here.

(*b*) Average core power densities for aircraft reactors must be considerably higher than anything produced thus far in other power reactor programs.

(*c*) Aircraft applications impose critical restrictions on reactor and shield assembly size because of the severe aerodynamic penalties imposed by large frontal area.

(*d*) The thrust-to-weight ratio of a nuclear powerplant suffers by comparison with present day chemical jet engines. To a degree this is offset by the weight of fuel carried by a conventional airplane, but this is distributed weight whereas the concentrated weight of the nuclear engine and its shielding introduces increased structural considerations in the nuclear propelled airplane. A more favorable comparison can only be attained by an increased thrust-to-weight ratio, or more simply stated, an increase in the high temperature capabilities of the reactor propulsion system.

The second consideration to keep in mind relates to the development approach which I believe must be followed in tackling the complexity of the task I have just mentioned. This I believe is twofold. First, we must maintain an intensive scientific and research effort in advancing fundamental high-temperature materials technology.

Second, and almost concurrently, there is a vast engineering and applied development job to be done in translating basic materials technology into the design and development of a high-performance reactor core and shielding system. It is the need for this latter area of hard-headed engineering and development testing which is not always adequately recognized. This effort involves component hardware, reactor core testing, and ultimately powerplant qualification through extensive ground testing and finally flight testing. It is most important that both the research and engineering phases of the propulsion program be maintained in proper balance and phasing to effectively achieve the objective of a useful nuclear powerplant.

In the direct-cycle program a very substantial effort has been devoted to the development of high-temperature reactor materials. We have at the same time conducted a series of heat-transfer reactor experiments with these materials as they became available in order to

resolve the many complex and varied reactor parameters such as heat transfer characteristics, power extraction and power distribution within the core assembly, pressure losses, and ducting problems. Active programs in the development of aircraft-type reactor control and shield systems have also been pursued.

I believe that there is general agreement that we are now in the position to build a prototype powerplant using reactor materials now in hand, which will sustain an aircraft in flight.

Flight testing of a nuclear propulsion system would provide useful test data for later systems of improved performance. Based on our progress to date we have established a flexible base of technology from which we believe we can proceed in the specific areas of application which may be determined to serve the best interests of our national security.

A more definitive delineation of these areas of application would facilitate the obtainment of these objectives. We have provided to the propulsion contractors those facilities which are necessary to a definable development task. We have in being an effective force of highly qualified scientific and engineering manpower which represents many years of experience in the ANP program.

I might add we are always seeking to improve that particular team of scientists because of the complexity of the problem, and the extreme difficulties they are experiencing in solving the problems they face.

In the management area we have provided for the centralized direction of the technical program.

Although my remarks have been concerned primarily with the direct cycle work, much of what I have said applies generally to the indirect cycle program at Pratt & Whitney as well.

There, too, facilities have been provided together with AEC funding necessary for the basic component research and experimentation which we believe is appropriate to the technological status of that system. We are interested in that cycle because of the attractive performance which appears to be inherent in the system, although possibly on a somewhat later time scale than the direct cycle program.

During the past 2 years, significant progress has been made in advancing the fundamental materials and reactor technology of the indirect cycle so that we are now in a position to proceed into the reactor experiment phase of that program.

From fiscal year 1950 through fiscal year 1959, the AEC has invested approximately $331 million in the ANP program, excluding facilities; of this, approximately $180 million has been invested in the direct-cycle effort, $134 million in the indirect-cycle area and $17 million in general support. The total AEC facility investment through fiscal year 1959 has been approximately $52 million.

I would like to point out that these figures are exclusive of the investment on the part of the Air Force or the Navy.

I feel that development and testing of a nuclear-powered aircraft will represent a very important scientific achievement. As we look back on pieces of equipment that have developed and have found their way into commercial and military application, they are often developed without clear-cut definition of their application, but once developed, their use became apparent.

I see no immediate commercial application for a nuclear-powered aircraft. However, there are some who feel that it might be an exceedingly useful machine in our whole long-range logistics problem.

One of the extreme difficulties in using a nuclear-powered aircraft commercially is the question of radiation. Not only protecting people that might be in the plane, but also handling the plane on the ground. This, I think, will always be a reason why its use commercially would be restricted.

It has been my hope that we could find a shortcut to flight testing by using an existing aircraft. However, the majority of agencies and individuals with competence in this area do not seem to believe that this is as useful or as desirable as proceeding with a new airplane designed specifically for nuclear power. The exact nature of the flight program, as well as the flight vehicle and subsequent military application, is, of course, the responsibility of the Department of Defense.

In the absence of a clear-cut determination of the characteristics of the first propulsion system for flight test, the Commission has nevertheless proceeded with reactor development toward higher and higher temperatures. A clearly stated first milestone toward which the program could be directed would, in my opinion, provide best assurance of its early attainment and would be a real stimulant to all personnel involved in the program.

That concludes my statement, Mr. Chairman.

Representative PRICE. Mr. McCone, I want to first publicly express to you my personal appreciation of the strong support that you have given this program since you have been with the Commission.

On page 5 you made the following statement: "I believe that there is general agreement that we are now in a position to build a prototype powerplant using reactor materials now on hand which will sustain an aircraft in flight."

Do you believe that it is desirable from a development point of view to proceed at this time with the construction of such a prototype powerplant for ground and flight testing?

Mr. McCONE. I think all things considered, sir, that to proceed with the program would stimulate this whole developmental program. I realize, however, that the decision in this respect is a decision to be made by the Department of Defense which is the using agency. It has been my suggestion that they try and find a way to utilize the reactor in its present status in an existing aircraft as a flying test bed. This apparently is not considered a desirable move, however.

Representative PRICE. We have had considerable debate on the definition in relation to a nuclear-powered aircraft and the word "useful." What would be your thinking in this connection of the word "useful" as it applies to the first nuclear-powered aircraft?

Mr. McCONE. That is rather a difficult question to answer. I have a feeling, as I have told this committee before, that there are a great many problems in connection with nuclear-powered aircraft other than the temperatures, and consequently the performance of the plane, which are of importance and must be solved. There is this whole question of the safe conduct of the plane and the handling of it on the ground. Really the marrying of nuclear power to flight, the opera-

tion of the reactor itself under flight conditions, when it is not steady, when it is turning, when it is subject to weather conditions, and so forth. All of those things have to be worked out. They may present problems that are just as serious and just as forbidding as the temperature considerations. Therefore, I would think that a reasonably performing plane could be very useful for demonstration purposes, although it would be of no use for most military missions.

Representative PRICE. I was also impressed with your paragraph 10 on page 6 in which you say that you felt that development and testing of a nuclear-powered aircraft will represent a very important scientific achievement, and then relating possibly to your own experience in connection with aircraft, you say if we look back on pieces of equipment that have found their way into commercial application, they are often developed without clear-cut definition of their application, but once developed their use becomes apparent. I think that is a pertinent expression in connection with the subject that we are discussing in these public hearings.

Do you believe that coordinated direction of the Defense Department and the Atomic Energy Commission effort on the aircraft nuclear propulsion program are an improvement over separate direction by each agency?

Mr. McCONE. Yes; I do believe that. I think it is necessary to have the developmental work that is a direct responsibility of the Department of Defense and that which is the responsibility of the Atomic Energy Commission coordinated through a single director. There are a great many reasons for that.

I think I have discussed this before with this committee. The two are so interrelated, just as they are in nuclear-powered submarines, that they cannot be very well separated at this stage of the game.

Representative PRICE. What do you think would happen if they were separated?

Mr. McCONE. I think that you would have gaps in the program, and you would find that the two would rather grow apart rather than growing together. I feel with the passage of time we would find the development of the aircraft and the turbine, which would be the Department of Defense responsibility, might not be completely compatible with the development of the nuclear reactor.

Representative PRICE. Has there been any suggestion recently that they be separated?

Mr. McCONE. Not to me; no, sir.

Representative PRICE. Have you ever heard of any, General Keirn?

General KEIRN. Not officially. There has always been voiced a view that it is awkward having a two-hat job, but there has been no official representation to me that there should be a divorce.

Representative PRICE. Would these discussions be the subject of concern, and we might have to guard against that?

General KEIRN. I believe there has been suggested that we reexamine the organization to see if there is any manner in which it needs changing, but nothing has been said specifically, to me at any rate, as to what the nature of these changes may be.

Representative PRICE. Senator Anderson.

Chairman ANDERSON. Mr. McCone, you say you have not heard any suggestion for separation. After I read what you said at the top of

page 5, I was going to make the suggestion that someone should separate them and let you go ahead with the development. A lot of us have felt we need somebody who is determined to get something built. I know your statement pleases many of us, particularly those three lines that I am sure Mr. Price referred to:

> There is general agreement that we are now in a position to build a prototype powerplant, using materials now in hand, which will sustain an aircraft in flight.

I think that is a fine statement. I commend you for it. We don't say that the materials now in hand are the only ones that will ever be used. But with what we now have we can go ahead and build one. I think that is what many of us have felt for a long time and would like to see done. I am very pleased with that statement, I assure you.

Then when you referred to the indirect cycle of Pratt & Whitney—this is at the top of page 6—you say:

> During the past 2 years significant progress has been made in advancing the fundamental materials and reactor technology of the indirect cycle so that we are now in a position to proceed with the reactor experiment phase of that program.

Mr. McCone. That is correct.

Chairman Anderson. You feel you can go ahead and do some work there as well as the direct cycle?

Mr. McCone. That is right.

Chairman Anderson. You would probably put the first emphasis on the direct cycle which seems to have gotten along very well but you could also go ahead with the indirect cycle?

Mr. McCone. I think that is right. I think in recent months the progress in the indirect cycle has been sufficiently encouraging to cause us to feel that it might come along faster and it might attain a better end point than the direct cycle.

Chairman Anderson. It could easily be. Some of us have seen some information recently that indicates that maybe we should have put more gamble on the indirect cycle or at least we are now ready to, and I am glad you have not closed your mind on it. In paragraph 10 on page 6, Mr. Price read the first two sentences. It just happened I underlined the third sentence:

> I see no immediate commercial application for a nuclear-powered aircraft. However, there are some who feel it might be an exceedingly useful machine in our whole long-range logistics problem.

You were around here in 1948 when the first contract was signed for a nuclear-propelled submarine. Your business has been the shipping business. Did you at that time see any commercial application for a nuclear-propelled submarine?

Mr. McCone. No, I did not at that time. Since then there has been some talk about it.

Chairman Anderson. But we built one anyhow and we now begin to see all sorts of applications. You inspected the *Savannah* before she went down the ways on Tuesday. You found it a very interesting vessel, did you not?

Mr. McCone. That is right.

Chairman Anderson. It begins to have some commercial possibilities, at least nuclear propulsion did, that did not seem apparent 10 years ago. I am happy to see that even though you see no imme-

diate commercial application you recognize that this thing might be worthwhile.

The last sentence here says—

A clearly stated first milestone toward which the program can be directed—paragraph 1—would, in my opinion, provide the best assurance of its early attainment.

Maybe I should not ask it just this way, but I will say on my own that I have felt sometimes that this first milestone was not very clear and still is not very clear. Some people keep thinking maybe we ought to wait until these materials are developed a little further and maybe we ought to wait to do this.

General Keirn was anxious to get flight testing underway, and that to him was a, I believe, first milestone. I hope you can use your influence in trying to see to it that we do clearly state that first milestone and get to work on it. Because if somebody does not, and we merely leave it in this nebulous stage, hoping that some new material will be developed, we will never have nuclear propulsion.

Mr. McCONE. I have no doubt, Senator Anderson, that improved materials will be developed in the not-too-distant future and that those materials, when developed, will make possible a very much improved flight version. I therefore can understand how those that are going to use the aircraft would be persuaded to hold off until this next development step is taken. I can understand that. It is quite difficult to argue against it. However, there are also persuasive reasons, some of which I mentioned, as to the advantages of getting along with the job.

Chairman ANDERSON. Would we not save time if we started to get a flight test vehicle ready? We could use it for direct or indirect. We do not know. It might be used for both. I think there is at least a possibility that it could. So whichever one got to the propulsion stage quickest might be utilized.

Mr. McCONE. Yes.

Senator GORE. If the Senator will yield, in connection with the promise of commercial uses of nuclear propulsion in ocean craft, I would like to read a UPI dispatch from London which was published today:

Britain announced today that she and Russia are leading the world in the race to produce electricity from nuclear-power stations, with the United States a poor third.

It seems we are in a race with France now.

Chairman ANDERSON. Look out for West Germany.

Senator GORE. I just wonder if it is not appropriate to call attention to our lag in the nuclear-power field since we seem to be lagging the same way in nuclear airplane construction. Did we not hear this morning that Russia might fly a nuclear-powered plane before the United States?

Chairman ANDERSON. I think that was a personal opinion offered by one member of the committee and I take no great responsibility for it. I believe Russia is getting along pretty well. I think General Keirn feels that Russia has done a lot of interesting work that might result in the development of a nuclear-propelled plane within 2 years, whereas we now have no first milestone that we are shooting toward.

That is why I was so pleased with Mr. McCone's statement. He would like to set up a milestone and try to drive toward it.

General Keirn wishes to do the same thing. I think it would be fine because we have lost some ground in some other fields, maybe not disastrously, but the one field where we made the greatest showing was in the nuclear propulsion of a submarine. That may be duplicated soon by other people. It may be copied or followed by them. Here is a field that we ought also to be moving along in. I thought the statement by the chairman indicating that he felt we could go ahead and build a ship even though it was not the last one that was ever going to be built, but suggesting that we build a prototype powerplant using reactor materials now in hand—I think that is fine. I think we will make improvements in material. But we have materials now in hand that we can go ahead with. We have all seen powerplants like the one at Dresden, near Chicago, employ the pelletized fuel quite a bit different than what they talked about at the beginning. Before they got the plant built they had materials better than they planned. Before this plane is probably ever ready to fly we will have improvements in the material. But the plane now with the materials in hand will fly, in the opinion of a great many people. I am greatly encouraged by your statement, Mr. Chairman.

Mr. McCone. I would like to comment, if I could, on this question of Soviet nuclear planes. I think any statement made by anyone as to when the Soviet might fly a plane is purely a matter of conjecture. I know of absolutely nothing. I don't know of anyone in the Government that has any dependable information concerning the Soviet nuclear-powered program. There has been a lot of talk about it. It is always held up as something to worry about. I have no doubt, as I have told this committee before, that they have a capability to do this. Whether they are doing it or not I do not know.

As far as I am concerned, I am not advocating this program or urging this committee to authorize one cent on it on account of what the Soviets are doing, because I don't know what they are doing.

Representative Van Zandt. Would you comment on the so-called power race that has been mentioned?

Mr. McCone. Yes; I would like to comment on that, too. I realize that the British have built and are building a substantial number of plants. They are doing a good job in meeting their own particular problem, but that is not our problem. We could build the plants that they are building. Every one would be a liability, and a serious liability, to this country. It would be nothing but cost to us for the entire life of the plant. It would be the greatest mistake we could make.

The British are doing a proper job from their standpoint for two reasons. In the first place, they have very high-cost fuel, and, secondly, they have to import a great deal of it. They can build nuclear plants and produce electricity very close to their cost, and also they reduce the amount of import of fuel and, therefore, they protect their currency balance. With respect to the Soviets, we know very little. We do know, however, that they have two problems that they have to answer. First, one is power and the other is plutonium for their weapons program. So far as we know, the majority of their plants, except their prototype work, is in the dual-purpose plants, primarily

for the production of plutonium for weapons. I think it is quite significant that Koslov told Admiral Rickover at Shippingport that they had been badly misled by their scientists on the cost of nuclear power and, therefore, they were not proceeding with it as a program. This is what Koslov told Rickover, and Admiral Rickover reported to me. They have found that nuclear power was much costlier than they expected. Therefore, they were meeting their growing power demands by conventional means, using coal, which is available to them in open pits at very low cost. He further went on to tell Rickover that they were not proceeding with their hydroelectric developments because of capital costs. I think that was quite significant as well. I will look forward with considerable interest to Admiral Rickover's report when he returns.

Senator JACKSON. Mr. McCone, did I understand you to say that they are not proceeding with their hydroelectric development?

Mr. McCONE. That is right.

Senator JACKSON. How does that stack up with the fact that our people have actually viewed these dams on Agana River and the Yangtze? One dam is 6 million kilowatts installed capacity, compared with our largest, which is Grand Coulee of 2 million. There is a whole series of dams that are going in. The Corps of Engineers testified in open session to the exact locations of all of these dams on the Volga, the Yangtze, and the Agana. Our people have seen them. We have pictures of them.

Mr. McCONE. That is right. I know that. Perhaps he is talking of their future program and their forward program rather than their current program.

Senator JACKSON. All I am saying is that our people have seen with their own eyes and Mr. Nixon will see it, too.

Mr. McCONE. I received an impression that they are reevaluating their means of meeting their growing power demands. I am merely reporting to you what Koslov told Admiral Rickover.

Representative VAN ZANDT. I might say that Admiral Rickover commented to me along these lines and said they were taking another look at their program of development of hydropower.

Mr. McCone, we have developed a reasonable amount of information, have we not, on the conduct of radiation in flight?

Mr. McCONE. Yes; we have developed a considerable amount.

Representative VAN ZANDT. In other words, we have actually flown an airplane with a reactor aboard, have we not?

Mr. McCONE. Yes; that is right.

Representative VAN ZANDT. We know something about the conduct of radiation at various altitudes?

Mr. McCONE. That is right.

Representative VAN ZANDT. We have provided $150,400,000 for the program this year, is that correct?

Mr. McCONE. I believe that is the figure.

Representative VAN ZANDT. What is our target date when we hope to have a functioning reactor?

Mr. McCONE. We have a target date on the first test reactor of early 1961.

Representative VAN ZANDT. To accelerate this program or to buy a little time, can you give us a cost?

Mr. McCone. You mean to advance that date?

Representative Van Zandt. Yes.

Mr. McCone. That date cannot be advanced.

Representative Van Zandt. Will you say that again?

Mr. McCone. That date cannot be advanced.

Representative Van Zandt. It cannot be advanced?

Mr. McCone. No, that date cannot be advanced.

Representative Van Zandt. In other words, if we were to put any more money into this program we would actually be throwing it away.

Mr. McCone. That is right, as far as that date is concerned.

Representative Van Zandt. We are talking about the reactor now.

Mr. McCone. That is right. That is this first test reactor which is scheduled to come in in the spring of 1961.

Representative Price. Mr. Chairman, are you certain of that date?

Chairman Anderson. Yes, because they came in and asked for more money. I do not know who they were kidding. Do you agree with that statement, General Keirn?

General Keirn. I believe you are referring to the fact that the total budget was something over what it was last year. The House appropriated a sum which is some $3.7 million less. Is this what you are referring to?

Chairman Anderson. We had a question this morning, General, about whether or not there had been a recommendation for a higher budget which was cut back. $101 million was cut back to $75 million. If they could not use any more money why did they come in and ask for $101 million?

General Keirn. This was not to accelerate this particular date; this was associated with getting started with a flight program.

Representative Van Zandt. Mr. Chairman, the next question would hove brought out the information the Senator is interested in. How much money is there appropriated this fiscal year to study the airframe for a possible aircraft?

Mr. McCone. Mr. Van Zandt, I do not want to interrupt your train of thought but I would like, Mr. Chairman, if I could, to straighten the record out a little bit on Admiral Rickover's statement with respect to the hydroelectric plants. I understand that his statement was not that there would be no more plants but that they were reviewing the amount of future hydroelectric as related to conventional coal plants because the cost of their hydroelectric plants was proving to be very high as compared to conventional plants. That was the context in which he mentioned that. I just wanted to straighten the record on that point.

Representative Van Zandt. Do you want me to repeat the question?

Mr. McCone. Would you do that, sir?

Representative Van Zandt. We are now talking about the cost of a step by step approach to the construction of an airframe in which this reactor can be installed. How much money is there in fiscal 1960 for this effort?

Mr. McCone. This is an Air Force question, and I don't think I have that information. I think the Air Force can supply that to you.

Representative Van Zandt. Maybe General Keirn can answer the question. Is it possible to accelerate the effort?

General KEIRN. Yes, that effort could be accelerated because we could initiate a phase 1 program on the airplane which we are not doing.

Representative VAN ZANDT. How much money will it cost us for the next several years to step up this program?

General KEIRN. I believe I gave the figures this morning that it would cost us about $340 million spread over 4 to 5 years, not evenly, but in total. This is over and above a level figure of about $150 million.

Chairman ANDERSON. Was the budget for 1960 originally $101 million for the Air Force, $98 million for AEC and $45 million to the Department of Defense? That involved early flight. The actual budget ended up with $150 million: $75 million for the Air Force, $75 million for AEC and nothing in the Department of Defense $45 million item. Are those not the figures you were using?

General KEIRN. Those were the correct figures at one time.

Chairman ANDERSON. Then there was some $290 million to be spread over 4 years. That is why I said I do not believe, or it would be proper to say that there was nothing else that could be done to accelerate the program because the approval had been given for these $240 million which were subsequently cut to $150 million.

Mr. McCONE. Senator Anderson, just so we are thinking alike here, the question was asked whether more money could advance the 1961 date on this test reactor. More money could not advance that date. Money in the program spent now might advance subsequent events. I might purchase now long lead time items which would advance your flight operation. But the question was, How could this test operation be advanced? You will recall, Mr. Price, I asked that question out at General Electric when we were there, and that was the response I got, much to my surprise.

Do you remember?

Representative PRICE. That is correct on the ground test prototype reactor.

Mr. McCONE. That is right.

Representative PRICE. What Senator Anderson is talking about is the coordination between the reactor program and the initial flight. The additional funds would accelerate that point.

Mr. McCONE. Yes.

Representative VAN ZANDT. We are discussing that right now.

Mr. McCONE. By spending more money in the AEC at the present time you can buy long lead time items for the flight models. By spending more money in the Air Force, you can start the developing of the plane. However, you have to look at it this way, and this is the problem that the Department of Defense and the executive department looks at, and that is once you start you have to realize where you are going and the bill is about $340 million over 5 years, in addition to the level expenditure of $150 million each year.

Representative VAN ZANDT. How many months or years are we buying with the approximately $340 million?

Mr. McCONE. With the $340 million?

Representative VAN ZANDT. With the additional money that General Keirn mentioned a moment ago. I think he said something about $340 million. How much time are we buying?

Mr. McCONE. That is building two airplanes over a period of 5 years.

Representative VAN ZANDT. How much time? Are we going to buy a year or 2 years of the present program? What is our target date at the present time?

General KEIRN. There is none.

Representative PRICE. That is the main point. It is difficult to tell how much time you buy because until a decision is made on a flight test you do not know how serious you are about this program. Once a decision is made to set a target date for an early flight program, then you have the show on the road and you might buy several years.

Mr. MCCONE. I think any day you start, Mr. Price, you are starting a 5-year program. If you start it this year, it is 5 years from now. If you start the next year it will still be 5 years from that time. It will be an improved version a year from now than it is now. But that 5 years is going to be consumed from your starting date, in my opinion.

Chairman ANDERSON. That is why I liked your word about setting a milestone and going to work. I think we have to do it.

Representative PRICE. Senator Hickenlooper?

Senator HICKENLOOPER. Mr. McCone, this may be a question out of your province somewhat.

Comparing the situation in 1947 and 1948 and 1949 when the NEPA project was operating with what many of us thought was only a lick and a promise rather than a vigorous approach, do you see the urgency today for a nuclear-powered airplane in the whole Military Establishment as compared to that time?

Maybe my question is a little unclear, but I point out that at that time we had no missiles, we had no refueling system for our airplanes; we needed long-range operational vehicles. Technology has changed since that time.

As I say, again, it may be out of your province. I do not want to ask you to pass an opinion on a matter on which you do not feel you are qualified or experienced enough at the moment to pass on, but I merely raise that question.

Do we need a nuclear-powered airplane to the extent that our believed needs at that time would indicate?

Mr. MCCONE. I would answer that in this way: I think the need of this airplane was less in 1950 than it was in 1947. I think it is less today than it was in 1950. The reason is that other weapons systems have come in and will meet most of the missions for which the plane was designed.

Secondly, the air defense systems make the plane more vulnerable than was thought possible in those days. For that reason, it is more limited in the missions it can perform.

Senator HICKENLOOPER. I can readily see the utility of a low-flying sustained-flight vehicle, such as an atomic-powered airplane for ocean patrol. A plane that can stay out for long periods of time without having to come back to refuel and things of that kind. I am not at all convinced that our need for such a plane in the general military delivery systems for weapons has increased. In fact, I wonder if it has not decreased much along the lines you may have suggested. I do not mean to put any words in your mouth.

Mr. MCCONE. That is my personal position. Of course, in my official capacity that is a question that is outside of my province. But that is my personal opinion, sir.

Senator HICKENLOOPER. I think that is all, Mr. Chairman.

Representative PRICE. Mr. Hosmer?

Representative HOSMER. I think this milestone phraseology you used caused some trouble. What it actually means, since we already have a target date for a test reactor, means the target date for nuclear flight. The last sentence in your statement.

Mr. McCONE. That is right.

Representative HOSMER. Is that what you are talking about?

Mr. McCONE. If we have a clearly established definition of what is wanted by the using agency, then we could work toward that to best advantage.

Representative HOSMER. What I am trying to find out, though, is do you mean, when you say milestone, a date by which we have a nuclear-powered aircraft in the air.

Mr. McCONE. I would think that the determination of the nuclear-powered aircraft in the air desired at a particular date would be the greatest stimulus to the research and development effort.

If, on the other hand, the determination is that a high-performance airplane is all that is wanted, then that should be stated and we could orient our program to maximum advantage to attain that end.

Representative HOSMER. You say a higher?

Mr. McCONE. A higher performance.

Representative HOSMER. A higher performance than this CAMAL concept, a supersonic airplane?

Mr. McCONE. A higher performance plane than can be developed from the now available material. What it would mean, sir, would be a greater emphasis on the development of materials that are considered in the future and maybe deemphasizing the further refinement of materials now available.

Representative HOSMER. In other words, you are not saying just what this milestone is, is that it?

Mr. McCONE. No.

Representative HOSMER. It could be a target date for an aircraft in the air?

Mr. McCONE. That is right. You have had differing statements from various people in the Department of Defense as to just what they do want. Admiral Hayward was speaking of the desirability of a turboprop. The Air Force on the other hand are emphasizing the importance of a jet. If we can get set exactly on what is wanted, then we can orient our research program accordingly.

Representative HOSMER. From what General Keirn said this morning, it is pretty clear that it is a jet rather than a turbojet that he can get up there first.

Mr. McCONE. That is right. There is no question that the direct cycle, which means the jet, is more advanced than the indirect cycle.

Representative HOSMER. This $340 million that you have been talking about, General Keirn, is that the CAMAL effort?

General KEIRN. That is the effort on the prototype airplane for a CAMAL. I want to be sure to differentiate between the experimental airplane and the CAMAL as weapon system.

The $340 million covers the building of two experimental aircraft.

Representative HOSMER. That does not include such things as fire control system or armaments, adequate radiation protection, and all that sort of thing?

General KEIRN. No, it does not include any of the weapon system components other than the normal communications and flight control kind of equipment.

Representative HOSMER. This is in essence a flying test bed.

General KEIRN. That is correct.

Representative HOSMER. Mr. McCone, I believe you said that it would take 5 years to accomplish that, is that right?

Mr. McCONE. Yes, that is probably the best estimate you can make at this time.

Representative HOSMER. If you double the money and make it $680 million you could not build it in 2½ years?

Mr. McCONE. That is right.

Representative HOSMER. That is just about it?

Mr. McCONE. That is right. That figure is drawn from the experience in developing other types of aircraft and you are familiar with the time cycle in developing aircraft.

Representative HOSMER. I have only one other question. I would like to know if you feel that this program is characterized by a policy of drift and indecision.

Mr. McCONE. I do not feel that is a fair appraisal of the way this policy has been handled. I think there has been a very considerable effort. To be sure, the progress has not met the hopes of some that have been enthusiastic for it.

On the other hand, as I have said in my paper and at other times, very substantial technological advances have been made and they have been made in the direction of solving problems which a great many people just refused to recognize existed as problems. They have been time consuming.

This has been compared a great many times with the nuclear-powered submarine. That has been one of the finest performances that I have seen in the development of any kind of a weapon system. On the other hand, this is a very much more difficult problem from the technological standpoint than a nuclear-powered submarine because of the temperatures involved.

Representative HOSMER. Thank you.

Representative PRICE. Mr. Chairman, would you say that the program has been characterized by prompt and quick decisions?

Mr. McCONE. No, I would not say that. I would not defend the program on that basis, sir. I think there have been one or two stop-and-go decisions that have hurt the program, but I do not think it can be characterized as purely drift and indecision.

Representative PRICE. Would you say it could be characterized as a program with clear-cut objectives?

Mr. McCONE. I do not know that I can answer that, sir.

Representative PRICE. Mr. Holifield?

Representative HOLIFIELD. Mr. Chairman, I would like to make one comment. I was in Rostov on the Don River in October 1957, and they were building a very large hydroelectric dam at that point. I saw it with my own eyes. I do not know whether they stopped it or not and whether they are reevaluating it.

I did see that. I did not see some of the others that I heard about. There was one thing that you mentioned which I think the record should show, the offsetting facts, and that was that all of the British

reactors are uneconomic at this time. I think we can also say that all the American reactors are also uneconomic at this time.

All that we are building are going to be uneconomic, too, when compared with our best grade of conventional plants.

Mr. McCone. Yes. I would not like to leave the impression with you, Mr. Holifield, that the British reactors are uneconomic in their own economy. I think they are serving a very useful economic purpose within their economy. But we have a different problem here, as you know so well. I think my statement would reflect that I said if they were built here they would prove to be uneconomic and a liability.

Representative Holifield. If we use the word "economic" in the sense of competitive on cost, I have my doubts if even in the British economy their reactors are economic. I have no doubts at all that any of our own reactors that we now have built or are now building will be economic in the sense of being competitive with conventional plants.

It is true that we are in a stage of development in both Great Britain and the United States. We are building these reactors in order to prove the technology and not because we believe they are economic.

Mr. McCone. I believe that is right. That is why I think our program and the program we are going to project is going to bring us out at the most desirable point from our standpoint. I think we will perfect reactors rapidly and we will not build a great many that will prove to be liabilities from a competitive standpoint.

Representative Holifield. That is a long subject and I will not go into that at this time.

That is all, Mr. Chairman.

Representative Price. Senator Dworshak?

Senator Dworshak. Mr. McCone, I did not hear the statement of the Under Secretary of the Navy, Mr. Bantz, before this committee, indicating that there is some interest being displayed by the Navy in developing nuclear-powered planes. So far as you know is there any duplication of effort between the Air Force and the Navy in this particular project?

Mr. McCone. No, I do not think so, Senator.

Senator Dworshak. The Navy is doing work that is not currently being done by the Air Force?

Mr. McCone. That is correct. I do not feel that there is duplication.

Senator Gore. You think this might possibly be the only exception?

Mr. McCone. I have not heard of the Air Force building a nuclear-powered destroyer.

Representative Price. Are there any further questions of Mr. McCone? Senator Anderson?

Chairman Anderson. Just before you leave the stand, Mr. Chairman, let me say again I think your statement is a fine statement and brings courage to all of us who have been hopeful of seeing some development along this line.

Representative Price. I support that, Mr. Chairman, and am pleased to have you before the committee.

Mr. McCone. Thank you very much.

Representative Price. The next witness will be the Honorable Thomas Gates, Deputy Secretary of Defense.

Mr. Gates, we are glad to have you before the committee.

Mr. GATES. Thank you, sir. Mr. Chairman, I have a statement; may I proceed?

Representative PRICE. You may proceed.

STATEMENT OF HON. THOMAS GATES, DEPUTY SECRETARY OF DEFENSE

Mr. GATES. Mr. Chairman and members of the committee, basically the major questions posed with respect to nuclear flight are four in number:

1. Is the potential value of a manned nuclear-powered aircraft such as to justify the high cost of development, production, and operation?
2. Has a military requirement for manned nuclear-powered aircraft been established?
3. What characteristics as to performance should be required for first flight; that is, merely the ability to sustain nuclear flight or something approaching useful military flight?
4. What weight should be given to the psychological value of first nuclear flight?

The testimony you have heard today indicates some differences of opinion among the witnesses on some of these points. Without going into any technical details, which I will leave to Dr. York, I propose to give you my views on these subjects.

First, in an effort to get an additional and fresh appraisal of the potential value of manned nuclear-powered aircraft, the Weapons Systems Evaluation Group of the Department of Defense was asked over a year ago to look into, in as much detail as possible, how nuclear-powered aircraft would fit into foreseeable defense needs. In the resultant study by that group many possible uses were considered, including bombardment aircraft, the CAMAL system, logistic carriers, aircraft early warning, and antisubmarine aircraft. Since the study sets forth in great detail the present and future operational characteristics of many competitive and complementary systems, it must remain classified. However, I can generally report the conclusions of this evaluation. They indicate that nuclear-propelled aircraft, which we can now predict with some degree of confidence, do not offer a substantial margin of improvement over chemically fueled aircraft. In making such comparisons it is necessary, of course, to estimate as accurately as possible the performance characteristics which may be attainable in the same time period from the various systems under study. It seems entirely clear that aircraft propelled by a nuclear powerplant, constructed of materials which are essentially in hand at the present time, would fall far short of the performance of chemically fueled competitors. With the successful application of materials now in various stages of development, it appears that for some specific purposes the nuclear-powered aircraft would have some, but not a substantial, advantage over its chemically fueled competitors when all factors are considered. The great advantage of practically unlimited range is well recognized. Range, however, is only one factor to be considered. Speed and altitude, and relative production, maintenance, and operational costs, powerplant life, and possible restrictions on base locations and flight routes are also important elements of a complete analysis of the problem.

From these comments the question may arise: If nuclear-powered aircraft do not show a substantial advantage over chemically powered aircraft for military missions, why is the Department of Defense pursuing the development at all? I think the answer is obvious. We cannot at this time see the ultimate in the development of the nuclear-powered aircraft nor even the chemically fueled aircraft. We may expect, however, that as better techniques and materials are developed, the time will arrive when the nuclear-powered aircraft will match the best performance characteristics of chemically fueled aircraft and, in addition, will have the advantage of relatively unlimited range. This, we believe, justifies the adoption of the development of the nuclear-powered aircraft as an important continuing project. A parallel situation existed when the development of the nuclear-powered submarine was initiated. At that time we did not conceive of its use as a carrier for a ballistic missile. We are quite aware that we cannot at this time visualize either the ultimate characteristics of nuclear-powered aircraft or all of the uses to which such an aircraft may be put. Here, however, I would point out one significant difference between the first version of the nuclear submarine and a possible first version of a nuclear-powered aircraft. Materials and techniques were at hand to enable us to build a nuclear-powered submarine which was distinctly superior to its conventional competitors. This is not true of the nuclear-propelled aircraft at this time.

I should like now to comment on the matter of established requirements. Previous witnesses have stated that the Air Force has issued a general operational requirement for a nuclear-powered aircraft. This statement is usually abbreviated to say that the Air Force has a requirement for such an aircraft. It should be clearly understood what a general operational requirement means. For the Air Force a general operational requirement or GOR, as it is called, is a statement of the operational characteristics required of a piece of equipment or a weapons system in order that such a piece of equipment or such a system may be worthy of application to one or more of the missions assigned to the Air Force. It is the basis for the expenditure of funds and effort on a development program. The Air Force has issued a general operational requirement for an aircraft meeting the requirements of the CAMAL mission. Such an aircraft cannot be produced without further development since a powerplant which can be built with materials essentially at hand would not meet the requirements of the CAMAL system. As you are aware from my previous testimony in this regard, the Joint Chiefs of Staff were requested to provide a military appraisal as to the proposed course of action which should be pursued in the development of a militarily useful nuclear-powered aircraft. I will refer to the guidance which I received from the Joint Chiefs of Staff on June 19, 1959, and which was entered into the record of the hearing.

Briefly stated, the Joint Chiefs of Staff expressed their conviction that there is considerable military potential in the nuclear-powered aircraft and that early achievement of the capability for nuclear flight would be in the national interest. They stated, however, that they were unable at this time to establish a military requirement for nuclear-powered aircraft or to define the specific weapons system for which it would be used. With respect to the future course of the devel-

opment program the Joint Chiefs of Staff advised that the present program should be extended to include flight test as soon as technically feasible. The test vehicle selected should be capable of testing any of the engines that may be developed and the program should enable the application of advances of reactor technology as they occur.

You will note that the Joint Chiefs of Staff feel that they are unable at this time to establish a military requirement for a nuclear-powered aircraft or to define a specific weapons system concept for such an aircraft.

I do not regard the issuance by the Air Force of a general operational requirement for a CAMAL type aircraft and the views expressed by the Joint Chiefs of Staff to be inconsistent. The Air Force has said, in effect, that if an aircraft meeting certain clearly defined specifications can be developed it would propose to use such an aircraft in the CAMAL system. The Chiefs have said essentially that it is too early for them to define a specific use for a nuclear-powered aircraft.

The third question upon which an apparent difference of opinion exists is the matter of early flight. Proponents of early flight, using a powerplant recognized to be inadequate for a militarily useful aircraft, point to many practical advantages of that procedure. These advantages are clearly recognized, but the disadvantages are also worthy of thorough consideration. For my part, since this is a research, development, and engineering program, I have taken the advice of the Director, Defense Research and Engineering, who is responsible to the Secretary of Defense for the evaluation of major programs of this character. Dr. York will inform you as to his views on this subject, in which I concur. I will repeat that I appreciate the importance of actual flight as an essential part of the development program as a basis for the development of operational techniques as well as for the evaluation of the powerplant. I also appreciate the fact that it is most unlikely that the first powerplant to be demonstrated in flight will fully meet the requirements of a useful weapons system.

The fourth question posed relates to the psychological advantages of first flight. The Department recognizes that some psychological advantage may accrue to the Soviets if they demonstrate successful nuclear flight before we do. However, the Department must give primary consideration to the application of its resources to providing for the national security by the development of means to deter aggression, and, if this fails, to wage war successfully. In an era when so much attention is being focused upon the conquest of space we seriously question whether an important psychological advantage would accrue from first nuclear flights at speeds and altitudes below those attainable by conventionally powered aircraft. In any case, it is our conviction that the psychological aspects in themselves do not justify a departure from an orderly program to develop a militarily useful vehicle which will contribute directly and importantly to the primary mission of the Department of Defense.

Now, I would like to discuss future budgetary plans in this important program. As you are undoubtedly well aware, in the development of new weapons and weapons systems we are faced with many difficult choices, not between a good weapon system and a bad one but, rather, among many good ones. We are trying every means at

our disposal to get the most for our research and development dollars, and we are forced to look in great detail at a great variety and scope of problems. The technical evaluation of our research and engineering program falls principally upon the shoulders of Dr. York and our various scientific advisory committees. Dr. York has advised me that in the national interest we should plan on funding the nuclear-powered aircraft program at somewhat greater than its present level. The amount of the increase will depend upon the progress made and the development needs. Thus we expect for at least the next year to program funds at a level somewhat greater than the present $150 million per year.

As a final comment I may state that I believe that the management of the aircraft nuclear propulsion program, which has been met with some criticism in the past, should be jointly reviewed by the Department and the Atomic Energy Commission. Unfortunately, I have not had a full opportunity since assuming my present job to give this matter the thorough attention it deserves. However, I expect to discuss this question with Mr. McCone in the very near future with a view to determining whether the present management system should be altered.

Representative PRICE. Thank you, Mr. Secretary.

What would be the purpose of this review that you suggest, a joint review by the Department and the Atomic Energy Commission?

Mr. GATES. The purpose would be to confirm whether we have the correct organizational type of management, whether we have representational type of management, whether we have representation on the correct level of the Air Force and the Navy, whether we have a situation like we had in certain of the ballistic missile problems that we faced, whether we set up a sort of board of directors type of management.

We have a Ballistic Missile Committee in the Department of Defense, for example. I do not know enough yet to recommend anything, Mr. Price, but there has been criticism of the management, and I think it ought to be reviewed, and if it needs changing I think we ought to change it.

I am sure there will be no trouble working this out with Mr. McCone.

Representative PRICE. Has there been criticism of the joint arrangement between the Defense Department and the AEC?

Mr. GATES. No, sir; I have not heard of any.

Representative PRICE. Has there been any consideration of dividing or separating this arrangement?

Mr. GATES. No, sir. This would be just a question of whether all interests in this program can be pulled together in a board of directors type of approach as opposed to the way we are doing it now. I do not say it is wrong now; I have just heard criticism.

Representative PRICE. We have fought for a long time for a single direction of this program. Is there any danger that this arrangement is threatened?

Mr. GATES. We hope we would only change it to improve it. I brought this up because I heard comments to this effect, and I thought I had been a little negligent in getting around to reviewing it, frankly.

Representative VAN ZANDT. If the gentleman will yield, Mr. Secretary, would this review bring about the type of management that is being applied now to the Polaris-type submarine?

Mr. GATES. It could.

Representative VAN ZANDT. That is a one-management job, is it not?

Mr. GATES. Admiral Rayburn is a special projects officer who reports to the Navy Ballistic Missile Committee as his board of directors of which the Secretary of the Navy is chairman. So, in effect, we violate the bureau system in the Navy and have a special organization for Polaris.

Representative VAN ZANDT. Is it proper to assume that the Polaris effort represents a national one?

Mr. GATES. Certainly; it is a program that has the highest national priority.

Representative VAN ZANDT. I should have said "national project with the highest possible priority."

Mr. GATES. Yes, sir.

Representative PRICE. What type of criticism of the management were you referring to, Mr. Secretary?

Mr. GATES. Mr. Price, it has nothing to do with our relations with the AEC. It had to do with whether we could pull the pieces togethr more effectively. Dr. York and I are both new in this picture and we thought we ought to make sure that this was getting the kind of unified direction that it deserved.

Representative PRICE. Could it be criticism that more appropriately could be directed to what the management had to work with in this program?

Mr. GATES. No; I do not think so.

Representative PRICE. Senator Anderson, do you have any questions?

Chairman ANDERSON. I would like to go to your statement on page 4, toward the bottom of the page:

> The Air Force has issued a general operational requirement for an aircraft meeting the requirements of the CAMAL mission. Such an aircraft cannot be produced without further development since a powerplant which can be built with the materials essentially at hand would not meet the requirements of the CAMAL system.

Will you read that in connection with Mr. McCone's statement at the top of page 5 where he says:

> I believe that there is general agreement that we are now in position to build a prototype powerplant using reactor materials now in hand which will sustain an aircraft in flight.

Do I understand it to be your position that unless the plane that is developed will fulfill the requirements of the CAMAL mission that you would rather not build it at all?

Mr. GATES. No, Senator Anderson; it is not quite that.

Chairman ANDERSON. It is just what you say.

Mr. GATES. No, sir; I say somewhere else here that I agree we will fly an aircraft before we have a specific weapons system. I agree that this will be done or will necessarily be done.

Chairman ANDERSON. We recognize that the first prototype—General Keirn said this is to be a prototype for the CAMAL mission—may

not be the final one. As I recall it, they built a prototype for the *Nautilus* before they launched the submarine.

Mr. GATES. Yes, sir.

Chairman ANDERSON. We do it all the time.

Mr. GATES. That is correct.

Chairman ANDERSON. Do I not understand from this that you are opposed to a prototype, that an aircraft cannot be produced without further development since a powerplant which can be built with materials essentially at hand would not meet the requirements of the CAMAL system. How do you interpret that except as discouragement?

Mr. GATES. We do oppose the building of a prototype airplane which we agree with Mr. McCone can now be built to sustain an aircraft in flight. We do not go so far as to say that we would not built a prototype airplane before we were completely satisfied that we would have a CAMAL airplane out of it.

In other words, I think I say also, somewhere in my statement here, something to that effect.

Chairman ANDERSON. In your statement, you say:

> With respect to the future course of the development program, the Joint Chiefs of Staff advise that the present program should be extended to include flight tests as soon as technically feasible.

Mr. GATES. That is their statement.

Chairman ANDERSON. Mr. McCone and General Keirn say it is technically feasible. Then why do you not do it?

Mr. GATES. It is a matter of performance, Senator Anderson. The performance just is not good enough to justify it at this particular moment.

Chairman ANDERSON. Did the Joint Chiefs say when performance can be guaranteed—I am using your words—or did they say that the present program should be extended to include flight test as soon as technically feasible?

Mr. GATES. Those are their words; but they also said they do not have a military requirement, so this becomes a research and development program and our research and development advisers determine the question of technically feasibile.

Chairman ANDERSON. And they decided it was not technically feasible?

Mr. GATES. They decided it was not technically feasible in the right degree of performance.

Representative PRICE. If the Senator will yield for a moment, just exactly what did the Joint Chiefs recommend?

Mr. GATES. It is quoted right here, Mr. Chairman, as accurately as you can quote it.

Representative PRICE. What did the Joint Chiefs want to learn from the first flight?

Mr. GATES. I think the Joint Chiefs want to have an airplane that has a possibility of greater growth than the prototype test bed that could be presently flown, as is agreed.

Chairman ANDERSON. Is that what they said? Is it classified?

Mr. GATES. No. I thought you asked me, Mr. Chairman, what they really meant. What they said is just what I quoted. What they have actually said is exactly the words quoted.

Representative PRICE. Not completely. Is it possible for me to read exactly what they did recommend? Could we show it to you?

Chairman ANDERSON. Could we show it to you and let you say whether it is classified or not? We got a letter from General Loper telling us what we could and could not do from the security standpoint:

> Program dates and capabilities are defense information which reveal present or future possible capabilities and must be safeguarded.

When they got to listing the things he said specific dates of operation, specific full-scale propulsion system. Apparently, the word did not get to Admiral Hayward because he used some of the dates. I am wondering whether the same regulations applied to the Navy as applied to the Joint Committee.

Mr. GATES. It should have applied more exclusively to them.

Chairman ANDERSON. That is why we would like to have you look at this and tell us whether it is classified. The AEC did not think it was classified. They did not have a classification officer here today.

Representative PRICE. Yes; they did.

Mr. GATES. I have no intention of misrepresenting what the Joint Chiefs said to the committee and I have tried to paraphrase exactly what they said. You will find the language identical with the letter. I have not tried to leave anything out. If I have, it has been inadvertent.

Chairman ANDERSON. I quote from the General Advisory Committee report of June 19, 1959—this is General Advisory Committee to the Atomic Energy Commission—

> The work by General Electric has now reached the point where it appears likely that fuel elements can be developed which will be capable of making the performance of the direct cycle reactor high enough to be useful for propulsion of military aircraft.
>
> If the Department of Defense is in favor of proceeding with this system, then the Reactor Subcommittee recommends that the necessary steps be taken to develop the XMA powerplants by General Electric and these steps include provision for flight testing and demonstration of these propulsion systems as proposed by General Electric and Convair.

Is it your testimony that your scientific group do not agree with that, or do they?

Mr. GATES. No; they do not in total agree with that. They were aware of this. They interviewed each of the members of that committee. Dr. York did personally, separately—separately and collectively, as he was able to see them.

Chairman ANDERSON. One by one. Did they change their opinions?

Mr. GATES. He can speak for himself.

Chairman ANDERSON. Can they not speak for themselves when they make a statement?

Mr. GATES. Certainly, sir.

Chairman ANDERSON. What persuaded them to change, if they did?

Mr. GATES. I don't think they did change.

Chairman ANDERSON. Then why are you not ready to go ahead with a test flight?

Mr. GATES. We, as I say, are relying on the best people we know how to obtain in the scientific world, including the director of our research and engineering program, plus our Scientific Advisory Committee, plus the President's Scientific Advisory Committee.

Chairman ANDERSON. You say the best people you can get?

Mr. GATES. There is obviously a difference of opinion between scientists.

Chairman ANDERSON. Surely you concede that the Atomic Energy Commission has some fairly good people around that know something about atomic propulsion.

Mr. GATES. Certainly, sir.

Chairman ANDERSON. And the General Advisory Committee has a working knowledge of atomic propulsion?

Mr. GATES. Certainly.

Chairman ANDERSON. You would have to measure up who you used against them. On what basis did you decide that your crowd knew and their crowd did not?

Mr. GATES. After the most thorough review we could give it and their opinion was considered by our crowd, as you express it.

Chairman ANDERSON. We finally got this statement this morning, a statement that it was a matter of the budget. It was not scientific at all. It was budget. Was that the real reason here?

Mr. GATES. No, I do not think so, Senator. It has been estimated that this cost would be an added cost of $350 million over 5 years. Everything is, in a sense, budget, but I do not think this is essentially a budget question. This is a question of a technical capability and resources of people as well as dollars.

Representative PRICE. Actually, on your own statement with respect to the future course of the development program, the Joint Chiefs of Staff advise that the present program should be extended to include flight test as soon as technically feasible.

We have had ample testimony from the Atomic Energy Commission itself that it seemed to be technically feasible. We have had testimony from General Keirn. I think we could have testimony from the people who are doing the job out in the field that the technology has advanced to the point where a flight test is now technically feasible.

Chairman ANDERSON. That is exactly the point I wanted to develop. I do think you ought to tell us on what basis this recommendation that it is technically feasible is tossed out. Apparently, you have had a decision.

Mr. GATES. It is tossed out, Senator, on the basis that, one, we do not have a military requirement as yet; two, while it is technically feasible to fly an airplane, the airplane we fly under this program is a very limited airplane in performance and flight both. It leads to nowhere as far as further development of the reactor that is flying is concerned.

While it will teach us a great deal about safety of flight, and teach a great deal about maintenance and all the problems that I agree are very difficult in connection with a nuclear-powered airplane, and will have to be accomplished before a weapons system is developed—I agree with Mr. McCone completely on this—it does not produce an airplane reactor that has growth potential for reasonable performance. It has very low performance.

Chairman ANDERSON. No one is arguing with you on that at all, Mr. Secretary. Mr. McCone pointed out that flight testing of a nuclear propulsion system would provide us full test data for later

systems of improved performance. Many of us know that in the development of the powerplant of the *Nautilus* that there was a land based prototype built. We did not have to say this thing must propel the *Nautilus* immediately without any preliminary testing.

You built one just as Mr. McCone seems to want to do here. There are many people who think that was followed in many other practices. I have even seen Dr. York come in with some designs for weapons that he subsequently changed and perfected.

It is not impossible for somebody to have one idea and improve on it later. You learn by experience.

Mr. GATES. This s absolutely true.

Chairman ANDERSON. What I understand you to say is that until it will do what CAMAL wants it to do, leave it to one side. The budget question did seem to come up in the testimony of Mr. Taylor this morning.

He finally got around to saying it was the budget that caused this to be cut down. I gave the figures a while ago of $100 million for Air Force, $98 million for AEC, and $45 million for DOD.

How did those go down to $75 million each for Air Force and AEC and zero for Department of Defense if it was not the budget? Was it scientific evaluation that brought them down?

Mr. GATES. This is not, in my judgment, a budget question except as everything is somewhat a budget question.

Chairman ANDERSON. My question was a budget question. It was $101 million for the Air Force in 1960; AEC, $98 million; and DOD, $45 million. When it finally got through the Bureau of the Budget it was cut to $75 million each for Air Force and AEC and zero for Department of Defense.

Was that not a budget action rather than a scientific action?

Mr. GATES. I do not think so. I was not in the Department of Defense at this time but I believe that this probably contemplated some of this early flight money.

Chairman ANDERSON. The first one did and the next one did. The first one involved some early flight. The other one says we will simply mark time until we start this so-called 5-year cycle—General Loper, if that is not a violation of regulations, but Mr. McCone used it so I will take a chance on it—if we mark time for 3 or 4 years, then we can start the 5 years at the end of that time.

We would like to start the 5 years now. Mr. McCone said, "Set up a milestone and let us drive toward it." I think this change from $250 million to $150 million had a budget face to it.

Mr. GATES. I do not think so, Senator. There was a difference of opinion whether we fly early flight or whether we proceed on an orderly program to develop a better reactor.

Chairman ANDERSON. And your scientific people told you that Mr. McCone was wrong when he said flight testing of a nuclear propulsion system would provide useful test data for later systems of improved performance.

That is based on the history of the Atomic Energy Commission in all its work from 1943 on or 1946 on, whenever it was set up. They do think you learn something by these things. They decided that you did not.

Mr. GATES. There was no question about the fact that you learn a great deal about handling nuclear power in the air and this is something you must learn and about the maintenance of the airplane and the radioactive problem and the problem of the crew and the problem of the basing of the airplane. There is no argument whatsoever about that.

It is a question of what you get out of the type of reactor you put up there. We do not believe we get very much out of that.

Chairman ANDERSON. Did you hear General Keirn—I hope if I misquote him he will correct me—he said you could use it for direct or indirect cycle and you could use it for improved materials that would be developed later on, so it would not be thrown away.

Mr. GATES. That is what is alleged that can be done.

Chairman ANDERSON. Do you not believe it?

Mr. GATES. I am not competent to question it.

Chairman ANDERSON. What do your scientific experts tell you?

Mr. GATES. The scientific experts want to build a better reactor.

Chairman ANDERSON. I know. But people learn to walk before they run.

Mr. GATES. In the case of the *Nautilus*, Senator, was it not true that the materials were on hand to build the *Nautilus* reactor and, of course, in the *Nautilus* reactor we were getting enormously increased speed and characteristics?

Chairman ANDERSON. I do not think the materials were on hand. It seemed to me they developed zirconium. Is that in accordance with your checking on it? We did not know all the answers in the beginning.

As I remember it, we put into the Atomic Energy authorization bill for this year, which the Senate is going to have a hearing on Monday afternoon, some money for a wholly new type of propulsion plant for a submarine that has fewer valves and various other things in it, a natural circulation system. We did not have a natural circulation system when we built the *Nautilus* or the *Seawolf*.

We started out with a different type of propulsion. We had to change it. You do not have these things all finished at one time. That is what I am trying to say. There are people who thought this might be useful.

Did you have any aeronautical expert who thought it was not useful to try out an airframe?

Mr. GATES. No; everyone agrees that at the proper time we should try out an airframe.

Chairman ANDERSON. When would be the proper time?

Mr. GATES. When we have a reactor that is possible of greater growth than the reactor we would have to use and concentrate on to fly this first airplane.

Chairman ANDERSON. If they think it is technically feasible to fly it with the materials now in hand, what is wrong with that?

Mr. GATES. The only thing wrong with it is that you do not get very much for doing it.

Chairman ANDERSON. Nothing but knowledge.

Mr. GATES. You get the knowledge on how to handle an airplane in the air. You do not get very much from the standpoint of sustained flight or performance.

Chairman ANDERSON. I think I keep going on over the same ground. It strikes me that if the people who have looked at this very carefully, and that includes General Keirn and Mr. McCone and his group, indicate that flight testing of a nuclear propulsion system would give us some useful information, it would seem possible we might go ahead and do it.

Mr. GATES. You realize, Senator, I am a completely lay person in this. In a research and development program, we must rely on the people that can best guide us. That is what we have done in this case.

Chairman ANDERSON. I realize that I am a completely lay person, too.

Mr. GATES. You have had a great deal of experience.

Chairman ANDERSON. That is why we have had the testimony of a general who had 22 years of experience in aeronautical design. I think you properly ask your people what plane they have designed that had perfect performance the first time it was tried out.

I saw some B–52's that had an awful lot of things wrong with them in the first stages; yet we built them and keep on building them. Many of the planes operate that way. Where would we have been if we had said we will never build the bomber until we know we have the absolutely perfect engine to go with it?

Mr. GATES. I am not saying that. I do not think this should be our position. I think we are talking about a little more time here to develop a better reactor and then go ahead and do exactly what apparently the Senator would like us to do.

This is a question, really, of a year or two of more work on these other components where we can get better performance rather than putting the work on this low performance which we all agree is possible to do.

Chairman ANDERSON. Maybe I can give you my answer to that best by pointing out that the Nike shot had no practical application. We were not sure how it was going to be used because it was a cumbersome heavy weapon that nobody could properly transport. But it is the first H–bomb just the same.

Nobody would try to put anything that weighed as much as the Nike shot in an airplane, I do not believe.

Dr. YORK. We didn't.

Chairman ANDERSON. Did it have a military requirement?

Dr. YORK. The hydrogen bomb did.

Chairman ANDERSON. I have been told repeatedly it did not have a military requirement at the time it was made. Yet, look what it has led to. All sorts of developments. I would like to see what would happen to this.

Representative HOSMER. Maybe we can get at this in the form of a hypothetical question, Mr. Gates.

The difference between this $150 million and the other figure that Senator Anderson mentioned, $244 million, is $94 million which, I suppose, is just about the cost of a Polaris submarine.

Suppose you got $94 million sitting on the table in front of you and it is your job to decide this year whether to buy another Polaris submarine or to throw the $94 million into this program. What would be your decision and why?

Mr. GATES. I would consult the Joint Chiefs of Staff but if you ask me for my opinion, and maybe we could use another system than

Polaris since I used to be with the Navy and might be accused of being prejudiced, I would try another system. I think we have more urgent problems today of immediate attention that would make better use of the resources rather than augment this program which we believe scientifically is on a sound basis and will lead to great deal greater expenditures in a few years when we go ahead and fly and so forth. If it was my permanent decision today, there would be a better use for the money within the Department of Defense.

Representative PRICE. Which would be a better use?

Mr. GATES. To put it in some other place than to augment this program.

Representative HOSMER. He does not like my Polaris example. He says he has something he would spend it on even more important than that.

Representative PRICE. If you adopt the philosophy that questior would seek to bring forth from you, you would just abandon all research and development programs, would you not?

Mr. GATES. No. I was asked whether, if I had the difference i cost between the program we have recommended and the progran that Senator Anderson referred to, that was cut back, and whether would apply it to this program or something lese, and I would appl it to something else.

Representative HOSMER. It is a matter of reasonable judgment i connection with the course and speed with which the problem ca be overcome to make a workable nuclear aircraft.

Mr. GATES. Exactly.

Representative HOSMER. As against some maybe developed typ of hardware that are needed to day for specific areas in the Defen Establishment, that may need to be peaked up.

Mr. GATES. Yes, and also in competition with other very vital r search projects.

Representative HOSMER. Also, as much as we like it we do not ha an inexhaustible supply of men and money for the Defense Depar ment and, therefore, of necessity, there must be some kind of priorit

Mr. GATES. That is correct. Irrespective of the dollars, it is o best judgment that this proceed with further research on building correct reactor susceptible of growth before we go ahead and fly airplane.

Representative HOSMER. I believe that is all.

Representative PRICE. Dr. York, you can present your stateme and then we will resume the questioning of Secretary Gates wh Senator Hickenlooper returns from a vote.

STATEMENT OF DR. HERBERT YORK, DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

Dr. YORK. Mr. Chairman and members of the committee, the aircraft nuclear propulsion program has been under way for 13 years. To date something over $800 million has been spent directly on the program, plus a good many additional millions on collateral projects that were charged to other accounts but justified on the grounds that they would be necessary for the ANP program, such as a test reactor

at Wright Field, Air Force contribution to the development of a large turbojet engine at Pratt & Whitney, and so forth.

Of this total, the Air Force's portion has been about $460 million and the AEC's about $380 million. In addition, the Navy has spent about $12.5 million, mostly in studies of applications and systems. Included in these totals are $166 million for facilities, the Air Force having spent $114.5 million and the AEC $51.5 million.

Between 85 and 90 percent of the total spent so far has been in the general area of propulsion work, with only 10 to 15 percent spent directly on airframes, systems studied and components, radiation effects, basic shielding measurements, and so forth.

Present technical situation: There are, as is generally known, two bascially different approaches to nuclear propulsion currently under development. These are: the direct air cycle system, being developed by the General Electric Co., and the indirect cycle system, being developed by Pratt & Whitney Aircraft. In the direct air cycle, the air which drives the propulsion machinery is heated by being passed directly through the reactor. In the indirect cycle system, a liquid coolant is circulted through the reactor and is then passed through an air radiator which heats the air to the temperature needed for propulsion.

Either the direct cycle or the indirect cycle can be used, in principle, to operate turbojets, turbofans, or turboprop engines.

In each case there is a design which makes use of "available materials" and there are designs in which it is intended to use certain "advanced materials." By this latter term, we mean certain materials which show considerable theoretical promise but which have not yet been shown experimentally to work under the necessary environmental conditions.

In our opinion, a powerplant of either type using the "available materials" could probably be used to propel a specially designed aircraft. However, we believe that this aircraft could not be considered as a militarily useful aircraft, and, furthermore, the particular powerplants involved would have little or no growth potential. On the basis of the theoretical predictions concerning the "advanced materials," there is, in our opinion, a real possibility that a truly useful nuclear powerplant could be built.

For reasons which we cannot discuss in detail here, we firmly believe that considering the different designs as they have been presented to us, the indirect cycle system, while intrinsically more complicated and somewhat further off in possible availability, is also intrinsically more useful. The technical effort in fiscal year 1959 was split about as follows: Direct air cycle, $103 million; indirect cycle, $17 million.

The problems which still remain to be solved are (1) the development of a reactor engine combination capable of producing militarily useful flight and (2) the flight testing of such a reactor engine combination so as to determine its behavior in flight.

Status of the requirement for ANP: Since first flight under the most optimistic conditions is some years in the future and since an operational capability which the military would be willing to depend on for important and useful missions would trail first flight by some years, it is obvious that such an operational capability is still quite

far off. Since no one can foresee what the military situation will be at that time, it is not possible to describe in any detail what ANP will be used for, although a number of disparate possibilities, including Camal, logistics, and various patrol uses have been proposed. Similarly, it is not possible to "prove"—as is sometimes attempted—by means of cost effectiveness studies based on present requirements that ANP will not be useful or competitive. A recent study of the Joint Chiefs of Staff solidly supported this view and said that while no definitive military requirement could be stated at this time the continued development of ANP is considered very important and potentially very useful.

A summary of the technical reviews of the program: The "Lexington Report of 1948" gave the results of a whole "summer study" devoted to ANP by a large group of experts. Conclusion (4) of that report stated:

> Development of the reactor is the outstanding problem. No materials which will assure that a reactor can be built to meet flight requirements are yet available. Reactor materials development combined with ingenuity is, therefore, the most critical need of the program.

This report then went on to say that the selection of a particular reactor should await full-scale ground tests of a number of possible types before selecting a prototype for aircraft application.

Eight more recent technical studies have been made by engineers, military personnel, and scientists under the following chairmen:

Assistant Secretary Furnas, December 1956.
Assistant Secretary Newbury, December 1956.
Mr. William Littlewood, February 1957.
Maj. Gen. W. M. Canterbury, May 1957.
Maj. Gen. J. S. Mills, June 1957.
Dr. R. F. Bacher, February 1958.
Dr. Abe Silverstein, May 1958.
Mr. E. V. Murphree of the AEC General Advisory Committee, May 1959.

In addition, the Air Force Scientific Advisory Board under the chairmanship of General Doolittle and later Lt. Gen D. L. Putt, as well as the OSD Advisory Panel on Atomic Energy, headed by Mr. Harry Winne, have frequently reviewed the program.

Without exception, all of these reports have emphasized the necessity of placing the main effort on reactor powerplant development. One of them—the Canterbury report—urged the earliest practicable exploratory nuclear flight, but that report also said there should be a stable program status for the next 4 or 5 years, with major emphasis on reactors.

On the whole these reports are remarkably consistent in recognizing the reactor problem as the one of paramount importance and most of them point out the inadvisability of a premature flight program.

Conclusions: I have also made an independent study of the ANP program, with the aid of several technically qualified members of my staff, having personally visited the Pratt & Whitney, General Electric, and Arco facilities and discussed the proposed airframe program with the Convair engineers on more than one occasion. Responsible Air Force, Navy, and AEC officials accompanied me on these trips, and entered into the discussions, as did other technical advisers from within the Government and from private life.

My conclusions are briefly as follows:

1. The capability for producing a reactor-engine combination suitable for militarily useful flight has not yet been established, but appears to be theoretically possible for both the direct and indirect cycle cases.

2. There is no definitive military requirement, but nuclear propulsion is judged to be of great potential military usefulness.

3. The state of the reactor materials art has reached the point where manned nuclear flight could be demonstrated by an aircraft of very marginal performance, but such a flight program, if instituted now, would have the following negative effects:

(*a*) The effort required would divert resources, including money, top rank manpower, and facilities from the more crucial and fundamental problems still requiring solution; namely, that of developing a sufficiently high performance and long-lived powerplant.

(*b*) Many of the experimental results and much of the experience which would be obtained from premature flight of a powerplant using interim materials, and of a possibly dead-end design, are very likely to be erroneous and misleading. Indeed, under extreme but possible conditions such premature flight could jeopardize the ultimate objectives of the program.

4. The "advance materials" versions of both the direct and indirect systems show sufficient theoretical promise so that both warrant concerted development programs, but neither has progressed far enough for a positive and reliable choice to be made between them.

On the basis of the above conclusions, and considering also the competition for available resources between this program and other important Air Force and Department of Defense programs, we have determined that the program objectives for the immediate future should be to—

(A) continue the development of only such reactors and powerplants as would be suitable for militarily useful nuclear flight;

(B) increase the effort on the indirect cycle program so as to determine its potentialities at an earlier date than previously contemplated;

(C) defer initiation of a specific flight program until—

(1) one of the advanced powerplants is established as feasible and potentially useful, and

(2) a flight program can be instituted without seriously interfering with the development of militarily useful powerplants.

Representative PRICE. Thank you, Dr. York. I was interested in your listing of the various committees that have studied this program. Of course, I have frequently commented that this program had been studied to death. It may be a little facetious but nevertheless, it seemed that when we got into a period when a decision should be made we would have had another study and a committee report.

I am very happy to be able to say that the last committee found themselves in agreement with the position taken by the majority of the members of this committee.

Dr. YORK. You are referring to the General Advisory Committee to the Atomic Energy Commission?

Representative PRICE. Yes.

Dr. YORK. Yes. I did, as has been said earlier, read their report, as you did, which said that they were impressed by the Camal mission and that they thought that if the Department of Defense were to decide that we should go ahead and fly that airplane, they would agree.

Representative PRICE. They said more than that, though, Dr. York. They said that work by General Electric has now reached the point where it appears likely that fuel elements can be deveoped which will be capable of making the performance of the direct cycle reactor high enough to be useful for propulsion of military aircraft.

Dr. YORK. Yes; I agree it is likely. That is what I said. The advanced materials do indeed appear promising and warrant a good healthy program.

Mr. RAMEY. This was not necessarily related to the advanced materials; I do not believe, Dr. York.

Dr. YORK. As far as the CAMAL system is concerned, I believe it was. They said, as of course I have said, too, that it is probable that the existing materials could be used to fly an airplane. After I read it, I invited them to come in and discuss this question with me, and we discussed it.

Three of them came in. We talked about it at some length, and I asked them two particular questions: "Suppose that the money were to remain the same, what would you do?" or "Suppose that there was to be a substantial increase, say $50 million or something like that, what would you do?"

Representative PRICE. You gave them a budget consideration?

Dr. YORK. I said what would you do under the conditions that the program remain the same or what would you do under a certain substantial increase. Where would you put the emphasis? They said that they would put the emphasis on the reactor.

Representative PRICE. That is probably correct. But this was a budgetary consideration.

Dr. YORK. It was a consideration based on the fact that the budget is not infinite. It was not based on necessarily tight control.

Representative PRICE. For instance, if you could have gotten $50 million additional from the budget, would you go ahead with the early flight?

Dr. YORK. Not on the basis of what I know about all the other things that other responsible groups, equally responsible with ANPO, would like to see going further. I think there are plenty of other good places for money besides this one.

Representative PRICE. You would place it on a priority consideration?

Dr. YORK. Yes; that does bear on the question.

Representative PRICE. You mentioned the Lexington report. This committee is very familiar with that because we have gone over it for a good many years.

Dr. YORK. It is 11 years old.

Representative PRICE. It is the basis of our original interest in the nuclear-powered program. I do not think anyone would differ with the conclusions. We have to remember that was back in 1948.

Dr. YORK. What they said is we ought to get cracking on the reactor problem.

Representative PRICE. No one disagrees with your statement that of paramount importance is the reactor. We all recognize that. We agreed on this quite some time ago. We urged high priority on the reactor program.

You state on the bottom of page 4, after you list these various committees, that without exception all of these reports have emphasized the importance of placing the main effort on the reactor powerplant development.

You mentioned only one of them, urging the earliest practical exploratory flight. Is it not a fact that the Mills report also recommended earlier flight?

Dr. YORK. I do not have it before me. Not in the same terms that the Canterbury report did. Everyone thinks we ought to fly soon.

Representative PRICE. Here is the Mills report. The Mills report recommends that program objectives should be early fabrication and flight testing of a prototype propulsion system in the early 1960's. The report noted that the problem of the propulsion system could only be solved through actual test flight, favored test aircraft as immediate objective.

Dr. YORK. It can only be solved ultimately through flight; indeed, it does have to be flown.

Representative PRICE. This particular committee favored it as an immediate objective also; that is, the flight test. This was back in June of 1957.

Dr. YORK. Yes.

Chairman ANDERSON. On page 6, Doctor, item (a)—

continue the development of only such reactors and powerplants as would be suitable for military useful nuclear flight.

I think I understand that. That means you would junk the GE experience with existing materials and the projected ground test; is that correct?

Dr. YORK. Of course you can't "junk" experience. Once you have the experience, you have it.

Chairman ANDERSON. If you turn away from it and do not use it, you neglect it. Use whatever term you want. It means you would turn away from all the GE work that was done.

Dr. YORK. No; that is not right. There is a substantial amount of GE work on advanced materials. There are, of course, other things about the reactor—control systems, critically, and all of that—which have been learned in the past.

Furthermore, there are what are called the HTRE reactors which are made with these existing materials, which are useful in connection with testing parts of the advanced materials reactor.

I would not turn away from it by any means. On the other hand, I would not build one to the point of making a powerplant out of it for the purpose of flight. To that extent, that is correct.

Chairman ANDERSON. What about the ground test that we covered at the same time?

Dr. YORK. Ground test of an engine; I would not do a complete powerplant.

Chairman ANDERSON. That would be interesting in connection with the *Nautilus* would it not?

Dr. YORK. No; that was built with the same material as was actually put in a working submarine.

Chairman ANDERSON. How do you know that these might not be, once you tested them.

Dr. YORK. I have good reason to believe that these materials will not have sufficient performance to give anything like militarily useful flight.

Chairman ANDERSON. To stay on this GE direct cycle.

Dr. YORK. In the case of the submarine, which is a very good analogy to us in connection with this program—analogies are never perfect, but this is a pretty good one—the first reactor put in a submarine used materials which gave performance which was substantially better than could be obtained with chemical fuels at the time.

Representative PRICE. What about at the time before it actually got in operation? What were the prospects? Were they absolutely certain of these things?

Dr. YORK. No. I don't really know. I don't think the situation was parallel in that there are solid reasons for believing that the existing materials would not be suitable to produce performance that would be superior to what you get with chemical fuel or anywhere near as good as what you can get. Whereas in the case of the submarine reactor, the first reactor that was used for propulsion was built with materials which did give superior performance compared to chemicals.

They did not build a submarine using the state of the art that was available earlier at the time when the thing was proposed.

Chairman ANDERSON. How much money would you estimate has already been spent on the development and fabrication of reactor materials presently available for early flight with a direct cycle propulsion system?

Dr. YORK. A substantial fraction of half of $800 million.

Chairman ANDERSON. Over $200 million?

Dr. YORK. Yes. It depends on exactly what you count. Whether you are counting materials research and developmnet, whether you also add in production techniques and production control methods and things of that sort.

Incidentally, quite a bit of this is applicable to some of the advanced materials, also.

Chairman ANDERSON. If you then continued the development, as you said, of only such reactors or powerplants as would be suitable for militarily useful nuclear flight, you would not take any advantage of the expenditure of more than $200 million?

Dr. YORK. That is not correct because many of the production procedures, and so on, and furthermore, the money that went into plant and facilities——

Chairman ANDERSON. You said "many of the production procedures."

Dr. YORK. Some of them can be taken over into the production of the advanced materials.

Chairman ANDERSON. They are entirely different materials, are they not?

Dr. YORK. Not all of them. In the way they are handled they are not entirely different.

Chairman ANDERSON. Do we know that they are not now?

Dr. YORK. We know of some very good candidates; one, maybe two.

Chairman ANDERSON. You have some candidates, that is all.

Dr. YORK. About which I feel quite optimistic. I think at least one of them looks pretty good.

Chairman ANDERSON. Does this relate to the language up above where you said:

The advanced materials versions of both the direct and indirect systems show sufficient theoretical promise so that both warrant concerted development programs.

Dr. YORK. Yes.

Chairman ANDERSON. Is it the difference between the theoretical scientists and engineers? The engineers who are working on this believe it is feasible.

Dr. YORK. Engineers can be theoretical, too, Senator.

Chairman ANDERSON. If it is theoretically all right, can it not be engineeringly all right, too?

Dr. YORK. I am not contrasting the word "theoretical" with the word "engineering," but the word "theoretical" with the word "proven" or "substantially proven" or "experimentally proven" or something like that.

It is not a contest between theory on the one hand and engineering on the other hand. Theory plays a good part in engineering.

Chairman ANDERSON. I really think it is because at the top of the page you say that—

Such a flight program if instituted now would have the following negative effects.

Dr. YORK. Yes.

Chairman ANDERSON (reading):

(*a*) The effort required would divert resources including money and top range manpower and facilities from the crucial fundamental problems still requiring solution, namely, that of a long-lived powerplant.

Dr. YORK. Yes.

Chairman ANDERSON. I believe this committee had testimony from both Pratt & Whitney and General Electric that you might be right on the question of diverting money but not top-rank personnel. They did not seem to think there would be any diversion of manpower by continuing this progam to early flight.

Did you hear any testimony to that effect from them?

Dr. YORK. I do not know what you mean by testimony.

Chairman ANDERSON. I thought you were at one time in the committee room while that testimony was given.

Dr. YORK. No, I do not believe I attended the JCAE at the time the testimony was taken from these people. However, this is my view whether the testimony exists or not.

Chairman ANDERSON. You think it would divert top-rank manpower in contradiction to the testimony of General Electric and Pratt & Whitney?

Dr. YORK. Yes. I do not say manpower. There is always manpower available. I am thinking here of top-ranked manpower, meaning the people who are most crucially needed to bet the job done.

Chairman ANDERSON. You do not mind tossing away the manpower of the General Advisory Committee's report on Mr. McCone.

Dr. YORK. I paid very good attention to it. I asked them to please come in and explain to me what they had in mind.

Chairman ANDERSON. You do in a contradictory sort of way. You pay attention to them like if somebody says to me "I think it is a good year," and I say, "It is a bad year." I have paid attention to the statement by contradicting it.

Mr. McCone said there is general agreement that we are now in a position to build a prototype powerplant using reactor materials now in hand which will sustain an aircraft in flight.

Dr. YORK. I agree that we could build a powerplant that would sustain—I prefer to use words like barely sustain or barely marginal—true enough, it will be off the ground. Of course, that is still more probable than certain.

Chairman ANDERSON. If it is off the ground flying at 400 or 500 miles an hour, it is not exactly a centipede.

Dr. YORK. I would not say it is a centipede.

Chairman ANDERSON. Mr. McCone said it would provide us full test data for later systems of improved performance from flight testing.

Dr. YORK. Only partially.

Chairman ANDERSON. Only a little?

Dr. YORK. Only partially. It would provide some. As I said in my next paragraph, I regard the distinct possibility that many of the results and much of the experience which would be obtained from a premature flight using interim results and possibly dead end design, are very likely to be erroneous and misleading. There is no question in my mind nor that of my principal advisers that there has to be flight of some kind of a prototype before there can be a weapons system.

Chairman ANDERSON. Who are your principal advisers?

Dr. YORK. I am talking about the members of my staff who are familiar with this subject and about other people that I have discussed it with.

Chairman ANDERSON. What members of the staff have worked on this? I ask that because General Keirn has had quite an experience. Mr. Shoults of GE has had a lot of experience. A lot of people know about these airplanes. I am wondering who these people are who told you these conclusions are erroneous.

Dr. YORK. Let's see. There are lots of conclusions involved.

Chairman ANDERSON. I am trying to find out who the people are who are involved. You said you took the advice of your advisers.

Dr. YORK. Yes.

Chairman ANDERSON. I am just wondering who gave you the advice that this would be a worthless thing to do.

Dr. YORK. It is not so much a question of whether it is a worthless thing to do. It is a question of whether it is a worthwhile thing to do, considering the availability of resources including money, manpower, and facilities.

Chairman ANDERSON. Phrase it any way you want to, who gave you the advice?

Dr. YORK. The people who are directly on my staff and involved in this are Dr. Biehl, Mr. Muse, and Mr. Jackson. Then there is a continuous round of discussions for the last few months on this problem between myself and a great many other people. I have discussed this with people on Dr. Killian's Committee. I discussed it with people in the Navy, with Admiral Hayward, of course, and with Assistant Secretary Charyk of the Air Force. I am not saying that each and every one of these people agrees with each and every one of the things I am saying.

Chairman ANDERSON. How much experience has Mr. Biehl had with the ANP program?

Dr. YORK. He has had substantial experience with reactors.

Chairman ANDERSON. We are talking about nuclear flight now. What is his background in nuclear flight?

Dr. YORK. Nobody has had successful experience with nuclear flight.

Chairman ANDERSON. On that basis nobody would be qualified.

Dr. YORK. No.

Chairman ANDERSON. Are you going to get down to people who have actually flown and used the airplane?

Dr. YORK. We talked with people who are expert in nuclear matters, materials matters, aeronautics matters.

Chairman ANDERSON. I am willing to take that definition.

Dr. YORK. There is not anybody who has had a successful career with the combination of all of these, and there won't be for quite some time.

Chairman ANDERSON. I am willing to take that. Mr. Biehl has had experience in nuclear matters. Mr. McCone drew on some people who had experience with nuclear matters.

Dr. YORK. Yes.

Chairman ANDERSON. You take Mr. Biehl against Mr. McCone on this matter. What is Mr. Biehl's past history that persuaded you?

Dr. YORK. I know him quite well. He worked with me at Livermore. He has since worked at General Nucleonics.

Chairman ANDERSON. Has he worked for any airplane company?

Dr. YORK. Yes.

Chairman ANDERSON. What company?

Dr. YORK. He has worked for both North American and Convair.

Chairman ANDERSON. And they hate to see a nuclear plane built, do they not?

Dr. YORK. Convair?

Chairman ANDERSON. They hate to see a nuclear plane built?

Dr. YORK. Are we talking about the same airplane company?

Chairman ANDERSON. You would call him a disinterested witness, then?

Dr. YORK. Yes. As disinterested as I am, disinterested from the point of view of having anything to gain. I am most interested myself in achieving nuclear flight. I think it is a very important thing and that is why it is the largest program we have in exploratory development that is not aimed for a specific requirement. We have lots of enthusiasm for this program and a great deal of interest.

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Chairman ANDERSON. The airplane companies take a dim view of this thing, and I am wondering if he is one of them.

Dr. YORK. I am sure it has nothing to do with his views in the matter.

Chairman ANDERSON. Do you know who Dr. Leverett is of GE and B. A. Schmickrath of Pratt & Whitney?

Dr. YORK. Yes.

Chairman ANDERSON. Have they fair experience? If they believed it would go, would you be persuaded that Dr. Biehl who has not made much study of it, would tempt you to believe his theory more than theirs?

Dr. YORK. As I said, I didn't just talk with Dr. Biehl, but with all sorts of other people, including Dr. Leverett. I gather that Dr. Leverett and I don't quite perhaps agree, but I have talked with him.

Chairman ANDERSON. You recognize that he does not agree with you, do you not?

Dr. YORK. He did not the last time I talked with him.

Chairman ANDERSON. Has he not sent you a note that he changed his mind?

Dr. YORK. No.

Chairman ANDERSON. You surely have not changed yours.

Dr. YORK. No.

Chairman ANDERSON. At the bottom of page 5, you said, "It would have the following negative effects."

Dr. YORK. Yes.

Chairman ANDERSON. Do you think it might be fair to explore to see if it had any positive effects?

Dr. YORK. I said earlier rather briefly in here because it has been taken by everybody that it is obvious that it is necessary to fly the reactor at some time in order to learn what are the problems of flight and problems of performance of the reactor in flight. I take that as being more or less obvious. Everyone has said so.

Chairman ANDERSON. I think that is all.

Representative PRICE. Mr. Hosmer.

Representative HOSMER. Dr. York, these four conclusions that you set forth you relate were arrived at after an independent study by yourself.

Dr. YORK. Yes.

Representative HOSMER. A scientific study?

Dr. YORK. A technical study. I don't know that the word "scientific" covers it.

Representative HOSMER. A thorough study.

Dr. YORK. As thorough as we could make.

Representative HOSMER. Did you talk with numbers of people?

Dr. YORK. Yes; I could not begin to estimate the number. Fifty, I would suppose, not counting the people who briefed me in a formal fashion.

Representative HOSMER. You were not born yesterday, and I suppose you would recognize anybody who would try to sell you a bill of goods.

Dr. YORK. I hope so. That is the objective, at any rate.

Representative HOSMER. Your conclusions were honestly and objectively arrived at.

Dr. YORK. Indeed.

Representative HOSMER. To the best of your judgment and knowledge?

Dr. YORK. Yes.

Representative HOSMER. After the conclusions in your statement you have the statement of the program objectives and you say, "We have determined the program objectives." Who are you referring to as "we"? I imagine you are talking about yourself.

Dr. YORK. That is right. This is some sort of a combination of an editorial "we" and meaning my office, as opposed to just myself as an individual.

Representative HOSMER. Who is your immediate superior?

Dr. YORK. The Secretary of Defense.

Representative HOSMER. And when he is not there?

Dr. YORK. The Deputy Secretary of Defense.

Representative HOSMER. Did they give you any instructions as to what conclusions you were to come up with?

Dr. YORK. No. They told me they hoped it would be the correct conclusions.

Chairman ANDERSON. Does that mean within the budget?

Dr. YORK. No.

Representative HOSMER. By correct conclusions, let us clean up the record on that one, what was your understanding of the meaning of the term "correct conclusions"?

Dr. YORK. Simply that it is important in the Department of Defense, which is charged with responsibility for defending the United States and the Western World, to come up with correct answers to all of the problems that face us.

Representative HOSMER. That is the right answer.

Dr. YORK. That is the right answer.

Representative HOSMER. Not an answer that is tainted by the budget or tainted by prejudices of one kind for or against anything or anybody, but what is right for the United States.

Dr. YORK. Yes.

Representative HOSMER. It is the best job you could do and you came up with this.

Dr. YORK. Yes.

Representative HOSMER. I believe that is all.

Representative PRICE. Senator Hickenlooper.

Senator HICKENLOOPER. Secretary Gates, I have some questions to ask you. It does not make any difference whether you or Dr. York answer them. They go to the same point. So whichever one of you wants to respond to these questions, it is perfectly all right with me.

As I understand it, the principal argument that you are making here is not that nuclear flight or some nuclear reactor that will sustain flight is not possible at the moment. We can build one that will, in fact, sustain flight.

Mr. GATES. That is correct.

Senator HICKENLOOPER. But that that particular reactor or instrument which is presently in hand will not be the type of reactor upon which we can enlarge into a useful nuclear reactor in flight. Is that correct?

Mr. GATES. That is correct.

Senator HICKENLOOPER. Further, that your proposals are that we should spend a little bit more time in the production of a prototype which can have possibilities and probabilities of being translated into an instrument that will be an actual useful military instrument in flight.

Mr. GATES. That is right, Senator. I don't think from a military weapons system point of view, or a really militarily useful airplane, we are going to talk about any different end result in time. It is a question of when you get to this nuclear first flight. I don't think there will be very much difference, from the best estimates I have been given, that the end result time will change very much.

Senator HICKENLOOPER. I understand. It is also your position, as I understand it now—I don't mean to put words in your mouth or to interpret your position unless it is correct—that the best interests of our military system, so far as a nuclear propelled airplane is concerned, will be served by going along the line of constructing a prototype which has possibilities and probabilities of being translated on that base into a useful instrument, rather than to take the odds and ends which we have at hand now and merely put a reactor into a plane that will furnish some power to sustain it while it is in flight but which will have very little, if any, possibility of being translated insofar as that instrument is concerned, into a useful propulsion system for a military vehicle.

Mr. GATES. That is correct, Senator, as far as the reactor is concerned. We agree with those who want to fly soon that we have a lot to learn from the airplane and the problems of handling. But as far as the reactor is concerned, you have stated it correctly.

Senator HICKENLOOPER. You can learn something from the airplane based upon aerodynamics and the location of the powerplant and all of those things which might develop special characteristics in this airplane.

Mr. GATES. That is correct. We must learn these things.

Senator HICKENLOOPER. There has been a great deal of discussion here about the *Nautilus* and the prototype of the *Nautilus*. It is my firm conviction that the prototype of the *Nautilus* was designed and intended to be a prototype which was almost exactly the same reactor and mechanism that would go into the vessel itself to make a useful vessel out of the *Nautilus*.

Mr. GATES. That is what I understand, Senator. Also in that case, you see——

Representative PRICE. Senator, I am sure you would not want to misrepresent the facts because this is true of what we have here, too, in the ground-test prototype.

Senator HICKENLOOPER. That is the exact distinction I am trying to develop here. It is not the same proposal. What is being proposed here, that is, the proposal that the Secretary seems to be speaking against, is the proposal not to build or a proposal which does not propose to build a prototype which can have the basis for being translated itno a usable military instrument. It is a gadget, in other words. You propose to take a little more time and develop the problems and the techniques for the construction of a prototype of a reactor upon which you can build a useful instrument. It is rather hard to draw that distinction, perhaps.

Mr. GATES. The airplane has this potential. The reactor does not.

Senator HICKENLOOPER. It is the reactor I am talking about.

Mr. GATES. We prefer to wait for the development and put our real effort on the development of a better reactor, and then go ahead, even before we have a weapons system established, and fly that reactor, as opposed to flying the reactor that we can fly first, and we agree with Mr. McCone's statement it can now be done. The airplane does have growth potential in its design as a test airplane.

Senator HICKENLOOPER. You are talking about the air frame now.

Mr. GATES. That is right, sir.

Senator HICKENLOOPER. As far as I am concerned, there is no argument on that point. But it is the question of the machinery that goes in there, the reactor part, and its operation. My understanding of this whole argument is that the urgency to get early flight is mainly to get some kind of reactor up there that will produce heat and a little power to push this plane along after it gets in the air by some other means so we can say we have an airplane using a little atomic power. We will learn something from that. I don't deny that at all. But I understand that you are working toward a reactor that is indeed a real prototype of a reactor or a reactor system that potentially can be built on for the production of a useful military vehicle.

Dr. YORK. Yes.

Mr. GATES. That is correct. It may be two types. I may be both direct and indirect.

Representative PRICE. Mr. Secretary and Dr. York, you would not want to leave the impression here that in going for the advanced materials, the entire reactor concept is being changed from what we are thinking about in the early flight concept?

Dr. YORK. Not the basic or the overall design. In some cases they are rather similar. In others they are not so similar.

Representative PRICE. And they can be used in the same flight vehicle.

Mr. YORK. It is possible. Convair has done a very fine job of coming up with the type of airplane that could use a reactor built with the available materials and could use hypothetical reactors built with advanced materials.

Senator HICKENLOOPER. I might suggest, Mr. Chairman, that I had not finished my questions.

Representative HOLIFIELD. I was just trying to develop a point.

Senator HICKENLOOPER. I understand. I was trying to develop a point myself, if I may.

Representative PRICE. You may proceed.

Senator HICKENLOOPER. What do you think as to the eventual time target for the production of a useful military vehicle, atomic propelled, as between the program which you suggest, and the program which is suggested that is based only on the psychological advantage, let us say, with a little technical information to get just early flight?

Dr. YORK. That question actually has two answers, even though it may sound like only one question. In the first place, we think that there probably is no difference in time with regard to—not getting first flight, of course, because that can be done quicker the other way—but getting a useful and important military system, I emphasize the word "important," because this is sufficiently expensive,

obviously, that unless it is important, we are not going to do it at all. That is, ultimately build a system. There is more to it than just that, though, and obviously it is guessing, because we are talking about a rather long time in the future. We are convinced that it will be a better system at that time. So it is not just a question of the dates, but it is a question of what you get at those dates. This, in a way, is all a matter of odds and judgment. Our judgment is that the odds are much greater that we will achieve a better airplane at about the same time. This time is quite far off, and is not to be confused with the time of either first flight or the time of first prototype. This is the time of a useful military system.

Senator HICKENLOOPER. In order to reach this goal of early flight without the use of a prototype upon which a military vehicle can be built—in order to reach early flight per se—wouldn't you have to divert scientific and technical skills away from the goal of a useful military vehicle? In other words, would you have to take a part of the technical and scientific skills away from that ultimate objective which otherwise could be devoted to the ultimate objective of a useful military vehicle?

Dr. YORK. Yes; that is, considering the kinds of resources and so on that are available to us. But more important than that, we think it is time to divert some further effort into solving the fundamental problems. It is a sort of double affair. It is not just a question that it would divert people out, but we would like to divert some people in.

Senator HICKENLOOPER. In other words, there are people working on just the early flight theory that in your opinion might well devote their energies and skill to the development of the eventually useful military vehicle?

Dr. YORK. Yes.

Senator HICKENLOOPER. That is all. Thank you.

Representative PRICE. Dr. York, do you think that these people whom you think so much of and who should be diverted into some other program consider themselves to be working on a useless program?

Dr. YORK. No, quite evidently they do not.

Chairman ANDERSON. I hope when we finish, Mr. Chairman, that we will ask Mr. Shoults of GE to state whether or not he has been spending some $200 million on a "gadget."

Representative PRICE. Mr. Bates.

Representative BATES. Dr. York, on page 2 of your statement you indicate that the present powerplants involved would have little or no growth potential. Can you tell us the reason for that?

Dr. YORK. I meant those that use the available materials.

Representative BATES. That is the sum and substance of it?

Dr. YORK. This has to do with the properties of the materials that are being discussed. We are not discussing the materials or their properties, but this has to do with the fundamental properties of these materials.

Representative BATES. This morning I asked a question but unfortunately we had a quorum call and I could not wait for General White to answer, concerning the first flight efforts. I am not particularly impressed by first flights. I think if it is a question of propaganda, it might be cheaper to get a better women's track team to com-

pete with the Russians. The question I asked this morning had to do with if the Congress appropriated fresh money to your shop for research and development, would you first put it into this project?

Dr. YORK. No.

Representative PRICE. Are there any further questions?

Chairman ANDERSON. I think while they are here, I would like to know if Mr. Shoults does not feel he should testify, since they have spent away over $200 million on this. I would like to ask him to come forward if he would and while Dr. York is still here, to state if this is a "gadget" or a real prototype reactor system that can be built for a useful military vehicle. I think it is a horrible thing to leave the impression that all of this money was used on a gadget.

Dr. YORK. Is that my word? I don't think so.

Representative PRICE. I see Mr. Shoults and Dr. Leverett right there, and I wonder if they have any comment to make with reference to their own project or on any testimony that has been given. I might start it this way. The question has been raised here as to whether the reactor powerplant as presently conceived has no possibility of growth until material developments are improved. I would like to ask someone from the project concerned, Mr. Shoults or Dr. Leverett, who have worked on the plant, to comment on this.

Chairman ANDERSON. You might say they are under no obligation. You have not been asked to come as a witness. You are certainly not going to be required to answer against your wishes.

Representative PRICE. This is not the first time we have done this. It has been common practice with this particular committee to seek comments in this way.

Chairman ANDERSON. Could you state your name and position?

STATEMENT OF D. R. SHOULTS, GENERAL MANAGER, AIRCRAFT NUCLEAR PROPULSION DEPARTMENT, GENERAL ELECTRIC CO.

Mr. SHOULTS. Mr. Chairman, I am D. R. Shoults, general manager of the Aircraft Nuclear Propulsion Department of General Electric Co. I have with me Dr. Miles Leverett, who is manager of the development laboratories of our department. He has been associated with the program since the days of the Lexington report.

I should like, Mr. Chairman, permission to read a very short statement which may be of some help in answering the question which has just been asked, and perhaps some of the others that you gentlemen may have in mind asking us.

Representative PRICE. You may proceed.

Mr. SHOULTS. We in General Electric Co. appreciate this opportunity to present our views at today's hearing on the development of aircraft nuclear propulsion. We share your conviction in the importance of this undertaking both to national defense and atomic energy development. Your committee's long-term interest in this program has been a vital and timely factor in our progress and of specific encouragement to all of us as individuals who have worked in it.

With regard to readiness for flight, let me first state to you that the General Electric Co. still believes that that program presented to many of you gentlemen at your request on April 10, when you visited us in company with Mr. Quarles, is a feasible program. It is desira-

ble from the point of view of powerplant development and can be attained on a scheduled basis with what we see as our current capabilities.

As has been stated many times we now have in hand the technology and capability to provide an aircraft nuclear powerplant of the direct cycle turbojet type which can perform in the air and on the delivery schedule which matches that for the design, fabrication, and test of an experimental airplane. This powerplant is currently in final design and initial stages of manufacture. It is currently proceeding to a full nuclear ground test.

In reaching this position the General Electric Co. has advanced the powerplant systems technology and hardware development for aircraft nuclear propulsion to a stage such that we believe that the only limiting factor on further development of the propulsion system is ground and flight testing data and not on any basic component or subsystems technology.

(1) The nuclear principles are well established on our shielding work, and the development work on special shielding materials has reached such a stage that its successful completion is realistically assured.

(2) Our control systems are laid out and have been simulated by analogue device, and the fundamental stability of these systems has been established.

(3) Our critical experiments and our many hours of nuclear-testing experience from HTRE (heat transfer reactor experiment) tests conducted at Idaho test station have provided sound experimental verification of both theoretical reactor physics and full-scale powerplant feasibility.

(4) Our reactor performance technology which deals with distribution of fuel and moderator in the reactor so as to produce an excellent distribution of power has progressed to the stage where reactor power is effectively flattened to the point where the local power level does not exceed the average by more than 7 or 8 percent.

(5) Our materials development for both fuel elements and moderator has progressed to the point where we now have demonstrated capability for these components to meet the initial powerplant flight-test requirements.

(6) Our advanced reactor technology shows particular promise of growth potential, even beyond the previously stated requirements for military usefulness.

(7) The turbo-machinery-testing program is progressing well in accordance with plan and the first endurance run has already taken place earlier this year.

(8) There have already been other benefits from this undertaking. For example, both reactor technology and materials derived from our program have significantly contributed to the Army package powerplant program (for portable electrical power sources), the nuclear missile (or Project Pluto) program, and the nuclear rocket (or Project Rover) program.

The first powerplant with which we propose to undertake flight testing—after ground-test checkout—is not an aircraft system fully developed for military operational use, nor is it intended to be. It is,

however, a flierable aircraft and is the next logical step in the engineering development of the nuclear aircraft system.

The desirability of having flight programed: Like any flight-propulsion undertaking, conventional or otherwise, a flight-test development program will permit the concrete determination of those factors which can only be fully evaluated by the powerplant's performance in the air under typical flight conditions.

We believe that actual flight testing is the only means by which it is possible to obtain the full range of systems information required, such as nuclear data and aeromechanical data. The sooner this data and experience can be obtained, the sooner those improvements can be made which will result in a fully operational system.

As flight testing and parallel development of advanced systems proceed, this flight test aircraft and the associated powerplant can grow to fly that regime of flight altitudes and speeds which others have defined as being militarily useful. This problem of usefulness is important. I will return to it later.

In regard to our philosophy of development, in proceeding through this 8-year program, the General Electric Co. has chosen engineering courses of action which promise to lead to earliest possible nuclear flight under conditions acceptable at the time. Our philosophy has been to keep as much simplicity, realism, and attainability as possible in an already difficult technical program.

In this development we have followed an approach which brings together the parallel development of all components and subsystems. This permits the achievement of a complete propulsion system with all subsystems at the proper level of performance in the shortest possible time and with the most effective utilization of funding.

From that earlier development phase where emphasis was on conception of principles and a search for practical methods, we believe that we have now progressed to a stage where our subsequent emphasis must now be placed on reducing such principles and methods to hardware practice.

Over the past 8 years, the General Electric Co. has overseen the expenditure of $457 million—slightly less than half of the total money allocated for aircraft nuclear propulsion development—in achieving the current state of the technology. The capability is now available and the next stage, flight testing, must be gone through if this program is to ultimately succeed in its original and current intention.

Usefulness of ANP and its relationship to establishment of a long-term objective. Although the determination of the "usefulness" of aircraft nuclear propulsion is not our responsibility as a contractor, we believe that, typically, new technologies have always given rise to expanded and previously unpredicted military usefulness.

Military utility, therefore, probably cannot be fully envisioned and its potential fully evaluated until after a nuclear aircraft has actually flown for a period of time.

Gentlemen, the need stands today for such a flight objective—as concrete and defined as possible. The ANP program, up to now, has never had this type of definite long-term objective which has stayed in existence long enough for it to be reached, and the program thus put in a position where a real evaluation of its potential could be made.

We, therefore, concur with that viewpoint which believes that the properly phased development of an experimental aircraft should be started now, and directed toward a definite flight date.

In summary, the General Electric Co. has always stood ready to serve the needs of our country as it is called upon to do so. Our chief executive officer, Mr. Cordiner, has stated that the company is ready to undertake those tough and highly complex technical jobs which it is particularly equipped to do.

For the past 8 years, we have believed that the aircraft nuclear propulsion program is one of these kinds of jobs. We are thus deeply appreciative of the understanding and dedicated efforts of you gentlemen and others who have helped this program on its way. At this point, I would like also to pay tribute to our own people who have enabled us to make so much technical progress.

With the type of support which you have always provided, we stand ready to pursue with vigor the next logical step in the development of nuclear-propelled aircraft.

To answer Senator Hickenlooper's specific statement, or Senator Anderson's, we feel strongly as individuals and from an organizational standpoint, speaking for the company, that we have spent to worthwhile objectives the moneys that have been given to us to spend to date. In the main, the moneys spent so far have been directed to the attainment of the technological capability to take the step that is now being discussed. It would be difficult to say, sir, that a major part of the specific moneys have gone into a particular fuel element or a particular other piece of hardware. We believe that the work to date has been useful and can be proven to be useful.

Chairman Anderson. Could I ask you one question in order to clear up my own situation? They have now passed around copies of the prepared statement. I had no knowledge that you had a statement of any kind ready. Did you tell me or have anybody else tell me that you had a statement ready?

Mr. Shoults. The statement was in the hands of your staff last evening, sir.

Representative Price. I might state to the Senator that I suggested in keeping with our normal practice if any representatives of General Electric or Lockheed or Convair or Pratt & Whitney were in the meeting as spectators, I might call on them.

Chairman Anderson. I do not mind that. I do not want it to appear that this was a byplay and that I had a previous arrangement with you to call on you for a statement. I did not have the faintest idea that you had prepared a statement or had one ready. Haven't you had some experience with jet engines, Mr. Shoults?

Mr. Shoults. Yes, sir.

Chairman Anderson. To put it mildly, a very substantial experience.

Mr. Shoults. I had my first introduction to jet engines when I met Frank Whittle in England in 1941.

Chairman Anderson. Is it your view—I want to try to get Senator Hickenlooper's words right—that this work you are doing is headed toward a real prototype of a reactor system that can be built for a useful military vehicle?

Mr. Shoults. That is my sincere belief.

Chairman Anderson. Do others in the General Electric group share that belief?

Mr. SHOULTS. I am convinced they do.

Chairman ANDERSON. I would not want to ask you to comment on Pratt & Whitney, but I believe their people have the same general feeling. You say that General Electric has overseen the expenditure of $457 million allocated for aircraft nuclear propulsion. How would you feel if after doing that there would be a decision to continue the development of "only such reactors and powerplants as would be suitable for militarily useful nuclear flight?" As I understand it, you are certain that the direct-cycle engine is going to be completely suitable for militarily useful nuclear flight. The only way I read this is that we drop the whole thing and go on to indirect cycle. How would you react to that?

Mr. SHOULTS. It would be very disheartening, sir.

Chairman ANDERSON. Do you think it would be wise?

Dr. YORK. As the author of that particular paragraph that is not what it was intended to say. I can well understand Mr. Shoults' answer to your question.

Chairman ANDERSON. I don't know what it was intended to say. I know what it does say. We have had testimony repeatedly, and you have contributed to it, Dr. York, that you doubt if this direct-cycle engine will produce a militarily useful vehicle.

Dr. YORK. That is the direct-cycle engine with the "available materials."

Representative PRICE. Mr. Shoults, what do you believe the importance is of directing this program towards a definite flight date?

Mr. SHOULTS. I believe in any such major development as this if you have determined that you believe in the feasibility of the development that you can only be effective in carrying it out if you do schedule it so that all of the people concerned can make timely decisions in the work that they do. I believe that we could go on for the next 20 years in this program and continue to make useful developments, discoveries, determinations, and so forth, but without the schedule of a specific date, we will always be, as Mr. McCone said earlier today, 5 years from flight.

Representative PRICE. In other words, if we don't put that first plane in the air, we will keep delaying the date when we will put the second generation up. We will keep setting back the date of the second generation.

Mr. SHOULTS. That in general is my experience in developments. You must take timely steps to realizeable goals and then attempt to build on those achievements good or bad as they may turn out to be, to better ones. Certainly the first jet airplane in this country was not at the time the equal of propeller driven airplanes that were built at that time.

Representative PRICE. Did the first jet plane have all the problems solved on the heat resistance of the various metals they used in it?

Mr. SHOULTS. Certainly not, sir.

Representative PRICE. You made the improvements and discoveries a lot faster after they started to fly?

Mr. SHOULTS. It is a powerful stimulus to solve problems when you can see the problem clearly face to face.

Representative PRICE. Mr. Holifield.

Representative HOLIFIELD. Mr. Shoults, I have not been questioning on this subject because I have not felt that I had as much background

of general knowledge on this as some of the members of the Research and Development Subcommittee. I want to say that I have a very high respect for your background of experience and also for Dr. York's. I was quite impressed by Dr. York's statement on page 2 in which he said:

> In our opinion a powerplant of either type, using the available materials, could properly be used to propel a specifically designed aircraft. However, we believe that this aircraft could not be considered as a miiltarily useful aircraft, and furthermore the particular powerplants involved would have little or no growth potential.

This is the specific point that I want to question you on. In the factor of growth potential, do you agree or disagree with Dr. York that the model which I have seen at Arco and examined has little or no growth potential? I wonder within the bounds of security whether we could discuss what we are seeking? I think we know we are trying to seek power in relation to weight. I know you have metallurgical problems. I think this is a very important point. If the models that have been made have little or no growth potential, then I would say that Dr. York would be completely justified in the next sentence of his paragraph where he says that—

> on the basis of the theoretical predictions concerning advanced materials, there is in our opinion a real possibility that a truly useful nuclear powerplant can be built.

He seems to indicate that there is a theoretical prediction that there are advanced materials which would attain whatever area of growth that you need or that you are so far away from the goal that there must be different kinds of material than that which you are using in existing models.

Within the bounds of security would you comment on that or would you want an executive session on that? I don't want to ask you any questions you should not answer in public.

Mr. Shoults. I will try to phrase it properly. I believe we are talking, when we talk about powerplant development, about a much broader thing than when we talk about specific reactor development. We are talking about turbojet engines and the like, and the mechanical combination of the reactor, engines, control systems, and so on. It has been our plan and philosophy of development to try to generate the mechanical systems control systems, and so forth so that they could be readily used with improved materials in the reactor itself.

We recognize that the first step is the reactor, and we agree with Dr. York that certainly improvement must be made if the ANP is to be a real success. The basic development hardware, it is our contention, must be made sufficiently universal that improvements in reactor technology can be incorporated with a minimum of change.

I think Dr. York will agree that this is our approach to the problem.

Representative Holifield. In simple words, would your answer be that you sincerely believe that there is a growth potential in what you have done which can be solved so that there would be a progressive refinement of your existing models and so forth perhaps by the substitution of advanced materials which are not yet available?

Mr. Shoults. That is correct.

Representative HOLIFIELD. When that occurs, you would achieve your goal?

Mr. SHOULTS. We believe that the goal of military utility in this basic powerplant is possible.

Representative HOLIFIELD. Do you agree that with the available materials you have that the finishing or putting this reactor into flight would be below supersonic speed—would of necessity have to be below supersonic speed—and would give you appreciable scientific information which you need and can't get otherwise in order to step this up to the militarily useful level?

Mr. SHOULTS. I believe that the time has come to schedule flights, and that we have the material in hand that can surely accomplish the first flights.

Representative HOLIFIELD. I think there is no argument there. Dr. York has agreed that you can sustain flight. That is not quite the point of my question. My point is, would the establishment of this flight and the sustaining of this flight give you the answers that you think you need in order to improve the present reactor engine assembly toward the goal of military usefulness?

Mr. SHOULTS. I feel it is an absolutely necessary step to get there.

Representative HOLIFIELD. Is it important that you have this flight on a sustained basis lower than supersonic speed in order to achieve the answers you are seeking?

Mr. SHOULTS. I believe so.

Representative HOLIFIELD. Dr. York, do you have any comment to make on that?

Dr. YORK. On your very last point?

Representative HOLIFIELD. On my general line of questioning which is based really on the statement that you made that the present setup has little or no growth potential.

Dr. YORK. The powerplant using the available materials has little or no growth potential. On the basis of theoretical predictions concerning advanced materials and so on, it looks very promising, and a truly useful powerplant could be built. Mr. Shoults and I have used a somewhat different choice of words and maybe with a different color on each one and maybe come out a little different way. When you change materials, this is not a small change. It is true that there is a lot of hardware that would be changed with it. But a change in materials in a reactor is not a minor thing. The only difference between a tennis ball and an orange is a matter of materials. The question of what you gain in making a flight with these available materials, the question of what you lose by making this flight by introducing the flight at this point, the question of how much of our resources in Defense are required to be diverted in order to do this, and how much of the resources and efforts required to be diverted from the advanced work within the program as it exists to be diverted, are all the things which enter into the question of whether now is the time for this flight. There is no question as to whether a first flight is needed, and there is going to have to be a first flight before there is a second flight. There is going to have to be a flight of something that works in some modest way before there is a later flight of something that works in some superior way.

Representative HOLIFIELD. I am trying to keep my line of questioning on the grounds of technical development without bringing into it this other factor which I know you as head of an overall agency have to consider, and that is the diversion of money and that sort of thing. In other words, I was trying to keep the budget problem out of this and keep it strictly on a technical basis.

Dr. YORK. I think Mr. Shoults does not disagree with this paragraph as written.

Representative HOLIFIELD. That does not mean that the budget does not come into it because I know you have to select projects with money.

Dr. YORK. Mr. Shoults is reading the paragraph. I think he may agree with it as it is written.

Representative HOLIFIELD. Mr. Shoults, would you care to comment further?

Mr. SHOULTS. I think that the real question before us is a question of judgment, and clearly a question of judgment as to whether now, with the capability at hand of achieving the first flight in an aircraft and powerplant configuration that would be useful for further development, whether the time has come to do this. Dr. York believes that perhaps this is not the time. I think on a judgment basis I tend to believe that now is the time to begin. I think we don't disagree as to the facts of the performance of the first power flight with the presently available materials. I don't think we disagree on the fact that there is a good promise of materials which would make this a truly useful system. We cannot say today that we have the ultimate materials firmly in hand, where you can with positive assurance schedule them and say that they will be used and that they will do exactly thus and so.

Representative HOLIFIELD. Do you believe that the job of scientific research and development is being done to produce these advanced materials?

Mr. SHOULTS. The work in the laboratories under Dr. Leverett's guidance is progressing with every means at our command.

Representative HOLIFIELD. Have you enough money to do that type of work? There is a limit in research and development as to the money you can spend on a specific project.

Mr. SHOULTS. In fiscal 1960, Mr. Holifield, I am not certain at the moment what moneys we do have. If we assume that we operate at last year's level, we do not have enough moneys to do all the things that need to be done for advanced systems and simultaneously meet the dates that were talked of earlier today. I believe someone quoted the spring of 1961. There is not enough money in a level program this year to simultaneously do both of those.

Representative PRICE. Unfortunately, I didn't get an opportunity to correct that misapprehension. I meant to do it because this date of 1961 for a ground test prototype is not borne out by the latest information we have in the light of the new approach to the program.

Representative HOSMER. Since this seems to be the crux of our problem here, I would like to bring it out in another way; that is, the difference between the engine that Dr. York is talking about that can't be built on and the one that you are talking about that can be. We are not talking about a thing like the difference between a reciprocating engine and a jet engine at all, are we?

Mr. SHOULTS. No, sir.

Representative HOSMER. Assume we are talking about a jet engine. If you go back 10 or 12 years ago on the material situation, then, we were pressing our limits on materials on the turbojet; is that right? Maybe it is a little longer than that.

Mr. SHOULTS. It has been fortunate in the jet engine business that turbine blade materials have just kept ahead of the need for temperature as determined by other considerations.

Representative HOSMER. Ten years ago we could not produce the jet engine that we produce today because we did not have the steel to go into those blades that would take the strains, stresses, and heat.

Mr. SHOULTS. I think if you examine the situation you will find that the turbine temperatures in jet engines have not really increased tremendously—certainly in subsonic propulsion engines—partly because the optimum temperature tended to be below the existing material limits.

Representative HOSMER. We are using a better type of steel, more suitable today, than we had available 10 years ago.

Mr. SHOULTS. I should think that the improvement in metallurgical materials in turbines has gone more to getting better life and longer life. A thousand hours instead of 100 hours.

Representative HOSMER. At least we have better materials, materials that have developed through the last 10 years and made it possible to get better life and performance than we have now. That was a build-on sort of thing.

Mr. SHOULTS. With the challenge of need and necessity.

Representative HOSMER. The only distinction we have here with this original engine is that there is not the build-on potential of the particular material in question whereas you mentioned other materials that are under development that apparently do have the build-on capability. In other words, what Dr. York and Senator Hickenlooper both had in mind was not that we are going to junk the whole concept or anything else, but we are awaiting a particular type of material that has a potential that we don't have in the reactor today. Is that what you had in mind, Dr. York?

Dr. YORK. That is a large part of it. In addition, there are the two different basic reactor concepts. One is the GE.

Representative HOSMER. That is something else.

Dr. YORK. We are trying to get a better fix on the difference in potenial between these two.

Representative HOSMER. You are not far apart on that. Not at least as a foundation for as much discussion as we have had.

Dr. YORK. Perhaps not as far apart as regards the discussion of the direct-air cycle.

Representative HOSMER. That is all.

Representative PRICE. Comment has been made here that you are not exactly junking the program. What in effect is actually happening?

Mr. SHOULTS. Currently, as far as our official instructions and contractual requirements are concerned, we have had no really new instructions based upon Dr. York's today announced decision. Our people at Evandale today are still driving toward the objectives that were held at the time that you were with us in April and Dr. York was with us somewhat later.

Representative PRICE. Let me ask you this question to resolve some of the points as to an early flight and the type of reactor you are going to put into the early flight airframe: Would several types of reactors be usable in the airframe that we have at least been thinking of in the design study?

Mr. SHOULTS. This is exactly the point of the program we have laid out. We can start with what we assuredly have today. As each new step of progress is made in reactor technology, giving us higher temperatures or lower pressure drop through the reactor, this can be incorporated as a change in the reactor part of the powerplant which after all is only one part of the powerplant. Considering the airplane system, it is an even smaller part there. We can make successive steps there without major change in the other components.

Representative PRICE. So while you may not have an add on capability in the reactor itself, you have the capability of using different reactors in the same air frame.

Mr. SHOULTS. Different reactors in the same airplane and different reactors in the same reactor-jet-engine a powerplant combination.

Representative PRICE. Dr. York, I would like to ask you this question. What, if any, decision has been taken on eliminating work on available reactor materials for an early flight in favor of more advanced material?

Dr. YORK. As far as we are concerned in the Department of Defense, I read at the end of my statement today the decision we had reached. Because of the fact this is a joint program between the Department of Defense and the Atomic Energy Commission, the details of this have to be worked out between the two agencies. In fact, the reactor directly is the responsibility of the Atomic Energy Commission. The rest of the system, the airplane and powerplant, Department of Defense. You can interpret this, if you like, as to being a statement as to what it is we will buy in the way of powerplant to put into an airplane. This has been transmitted previously to the Air Force, the Navy and the Atomic Energy Commission, but there has not been time yet evidently to act on it.

Representative PRICE. How much delay will there be in the nuclear flight program if these changes in the program are made?

Dr. YORK. It depends on what part you are talking about. First flight, a year or two, perhaps even more if nature just simply won't give up her secrets fast enough.

Representative PRICE. Would you say it would be at least 2 years?

Dr. YORK. I think it is likely to be at least 2, but it could be not that long. It just depends on how things go.

Representative PRICE. It could be more?

Dr. YORK. It could be more. If our contractors can't build a reactor there is no way we can make them or make it so that it can be done. It could be more. That, of course, is talking about first flight. I earlier expressed my opinion with regard to arriving at a useful and important military weapon system and further expressed the opinion that time would probably not change much, but in addition we would increase the odds of ending up with something which was more useful at the time. Prototype is a sort of intermediate system. Weapons system prototypes is intermediate. A delay somewhere between 1 year and 2 years. First flight, 2 years.

Mr. RAMEY. Dr. York, you said there was no way you could make your contractor achieve that.

Dr. YORK. Achieve certain performance, that is right. That is up to the facts of nature.

Mr. RAMEY. We have testimony from the Commission and from General Keirn and others that you can help the contractor achieve something if you will give him a target date. What we have learned today is that the target date on nuclear flight is gone, and the target date on the ground test experiment is gone.

Dr. YORK. I used to be a contractor myself. I would rather be told what the performance wanted was rather than the date. You cannot specify both, no matter who you are. You can either pick a date or performance. You cannot specify both. I myself would choose performance and that is the way I intend to try to do this.

Representative PRICE. It is helpful performancewise to have a target to shoot at.

Dr. YORK. Whenever a contractor then gets a program he then of course makes out a schedule of events. He does this as far in the future as he believes he is capable of doing. But he cannot guarantee those. He certainly can't be ordered to meet them. As far as what it is the Government should specify is concerned, I am saying that the Government should specify performance, always of course with a certain amount of latitude, because you don't always come to exactly what people ask for.

Representative BATES. Mr. Shoults, I want to say that I was very, very much impressed with our visit to Cincinnati. I went out there to see a contractor but I came back with the feeling that I had seen very dedicated people who had tremendous interest in this work. I want to be absolutely frank. After you showed us those movies and also your other programs, my enthusiasm for this so-called first flight somewhat dampened. The thought occurred to me that if we have such great prospects down the road, why don't we direct our efforts toward that rather than putting the odds and ends together and merely accomplish a stunt? I know you folks have a problem. You have been working on this a long time. The payoff is when you get something in the air. I can understand the feeling of your people with respect to that. I did have the feeling as I left there that the prospects in the future looked so bright for something that meant something, why should we settle for less in the immediate future if over the long run we can accomplish much more by taking the jump at this time.

Mr. SHOULTS. Mr. Bates, it seems to me that if we consider the parallelism of this development with turbojet or any turbine engine development, we are really talking about the reactor as equivalent to the combustion chambers in a jet engine, and the rest of the machinery tends to be somewhat the same. In the main the great majority of problems in any turboengine system is in other than the combustion system. I think the development of a purely useful nuclear powerplant will be in major part the problem of the refinement of detail of design of parts other than the reactor core.

In respect to other parts of the system we have yet to get experience with flight type shields. We have run HTRE experiments which tested reactor core parts. Reactor shields of flight design essentially

have to be built and we must gain experience with that problem which I can assure you has its own difficulties. One of the reasons why we feel so strongly that the support of a ground test at a specific time is worthwhile is that it lets us face up to the problems that we must meet and surmount beyond just the reactor core. The shield, the controls, the startup systems, radiation damage of all parts of the machine, amplifiers, lubrication systems, the ability to handle remotely repair as necessary, all of these are necessary parts of an orderly development program. They go beyond the specific business of just developing a reactor. If we had the reactor today we would have a tremendous job still to bring in the powerplant on a useful basis on a very good time scale.

Representative BATES. Your feeling is then that this is not a stunt. This is not propaganda. This is something that in your judgment should be done now?

Mr. SHOULTS. As a logical part of the development of a nuclear powerplant as opposed to a nuclear reactor.

Representative HOLIFIELD. If the gentleman will yield, when you say there are problems besides the core, are you perhaps thinking about the problem of concentrated weight of a reactor and the structural supports necessary to land a plane and that sort of thing?

Mr. SHOULTS. I think that is the airframe builder's problem. I think he is perfectly capable of dealing with it. He knows how to deal with it. In the design of Convair's model 54 they have dealt with it.

Representative HOLIFIELD. They have dealt with similar concentrated weights that would be required by the shielding around the reactor plant?

Mr. SHOULTS. I am sure they have.

Representative HOLIFIELD. Some of our testimony today was because the extra weight of the fuel was distributed over the plane's structure in the conventional airplane. While your overall weight might be slightly less than the conventional weight plus its fuel, there would be a concentration of weight by the reactor because of the intrinsic weight and the shielding involved. I wonder if these problems have been solved in the airframe?

Mr. SHOULTS. My belief is that the problems are susceptible to direct engineering analysis and design and they have been solved.

Representative HOLIFIELD. Your thought is that you have to actually build it and put one of these model reactors in to know where you stand?

Representative PRICE. We have a representative from Convair here who has a design study. I wonder if he would comment on that question? Dr. Kolitinsky.

Dr. KOLITINSKY. Thank you. We have prepared a design proposal of an airplane which is designed specifically to support a concentrated load without compromise.

Representative HOLIFIELD. I am sorry, I did not get that.

Dr. KOLITINSKY. The design of the airplane we have proposed is specifically designed to support the concentrated load without undue penalties in the structure or the aerodynamics of the airplane. We have had some experience in supporting concentrated loads in the B-36 which we flew with a reactor, shield, and a shielded crew compartment. We believe this problem can be taken care of.

Representative PRICE. Thank you very much.

Are there any further questions? If not, thank you, Mr. Shoults.

Dr. York, I hate to keep you people here this late, but we wanted to conclude the hearings. I understand Mr. Schmickrath, manager of the Pratt & Whitney project on the indirect cycle, is also here today. If he would care to make any comment or submit a statement to the committee, we will be glad to have it. I might say that applies to any other contractor, Lockheed or Convair.

STATEMENT OF B. A. SCHMICKRATH, PRATT & WHITNEY AIRCRAFT CORP.

Mr. SCHMICKRATH. I am sorry, Mr. Chairman, but I have no prepared statement to read at this time.

Representative PRICE. If you care to submit a prepared statement to the committee later on, you may do so.

(The statement referred to follows:)

SUMMARY OF THE CURRENT STATUS OF THE ANP PROGRAM AT PRATT & WHITNEY AIRCRAFT, AUGUST 17, 1959

Since early 1958, Pratt & Whitney Aircraft has been engaged, under the sponsorship of the Atomic Energy Commission, in research and development work aimed solely at development of nuclear reactors for use in militarily useful powerplants. The primary objectives of this work have been the development of materials and alloys suitable for use under extreme conditions and the advancement of nuclear reactor technology to permit attainment of extremely high nuclear system performance in terms of small size, low weight, and high temperature. Very good progress has been made in this research and development work, and the results obtained thus far provide ample justification for proceeding to design, fabrication, and operation of an experimental nuclear reactor. This project has been proposed to the Atomic Energy Commission, initial phases of the work are underway, and we have been advised that final project approval will be forthcoming in the near future.

In addition to militarily useful manned aircraft systems, the advanced technology which has been acquired is uniquely suitable for application to other scientific and military requirements for nuclear powerplants where compactness, high temperature, and long operating lifetime characteristics are of primary importance.

As previously announced by the Navy Department, work on development of components required for transfer of heat from the nuclear system to an aircraft engine is being conducted by Pratt & Whitney Aircraft under contract to the Navy, and additional work of a similar nature is to be supported by the Air Force.

Specific accomplishments in the research and development work include the development of materials and alloys with characteristics of complete corrosive resistance in extreme environments at very high temperatures, development of alloys with many-fold improvement in physical and mechanical properties at high temperatures as compared to conventional high temperature materials, extensive development of fabrication technology for new materials and alloys, development of high temperature nuclear fuel systems and structural assemblies, determination of neutron physics characteristics of advanced reactor design concepts, completion of preliminary design of an experimental reactor system, and the design and construction of prototype components of liquid metal heat transfer systems.

Work by Pratt & Whitney Aircraft for the Atomic Energy Commission, the Navy, and Air Force is expected to be continued along these lines at an expanded level of effort. We expect that a vigorous engineering program will permit the establishment of a feasible powerplant design suitable for militarily useful nuclear flight based on the technology now in hand and that intensive research effort in still further advancing fundamentad high temperature materials and nuclear reactor technology will provide the state of the art required for develop-

ment of even higher performance nuclear propulsion systems. Exploitation of the technology which has been developed for application to future military and scientific requirements for nuclear powerplants can be expected.

Mr. SCHMICKRATH. As far as the Pratt & Whitney program is concerned, we for the past 2 years have been in the position that Dr. York has indicated in his prepared statement. In other words, we are in the advanced reactor research and development work. We shifted over to this 2 years ago this coming August. We have accomplished during this 2 years enough work to justify a reactor experiment which I believe the committee and the Commission and Dr. York are familiar with. This is starting at this time. The problem of early flight for this reason does not affect us. This problem will face Pratt & Whitney when we have done enough work on this experiment to justify a flight program.

Our flight program, when it does come, and I am sure it will, will be a prototype system. It will not be an intermediate system. It will be a system with the ultimate potential that Dr. York has recommended in his report.

That is about all I have to say, Mr. Price.

Representative PRICE. How far away would you say that might be?

Mr. SCHMICKRATH. Three to four years.

Representative PRICE. The prototype?

Mr. SCHMICKRATH. The experiment completion will be 3 to 4 years, and it will be at that time we will probably discuss the flight program. It is an advanced system.

Representative PRICE. A decision has been made on that?

Mr. SCHMICKRATH. The verbal decision has been made. The formal paperwork is not all through. We have verbal approval within our present scope of work to start work on this experiment and the funding has been programed for this purpose.

Representative PRICE. In what amount?

Mr. SCHMICKRATH. This present year we will have roughly—to go back, we had $16 million this last fiscal year not counting equipment—we will have between $22 and $23 million in this fiscal year. It will then go up to $30 and $35 million the next fiscal year.

Representative PRICE. That is a pretty limited amount in the field of reactor development. Does that mean there will be 1, 2, or 3 years before you make a decision to go into flight testing?

Mr. SCHMICKRATH. About 3 years.

Representative PRICE. Before you make a decision?

Mr. SCHMICKRATH. This is the advanced system. It is not the intermediate system.

Representative PRICE. Are there any questions? If not, thank you very much.

The committee will adjourn.

(Thereupon at 6 p.m., Thursday, July 23, 1959, the hearing was concluded.)

APPENDIXES

Appendix A

Aircraft Nuclear Propulsion Program

CHRONOLOGY

1946

May.—First study project is initiated to explore feasibility of nuclear powered aircraft. This was the so-called NEPA project (nuclear energy for the propulsion of aircraft) undertaken for Air Force by Fairchild Engine & Airframe Co. Project located in Oak Ridge shortly after its inception.

1947

December.—Research and Development Board of the Defense Department recommended that the NEPA program proceed on a priority basis as a single unified and coordinated project with AEC.

1948

January.—President's Air Policy Commission recommends in its report ("Finletter Report") that steps to intensify research efforts on nuclear plane be taken immediately.

February.—Joint Committee holds first of 36 meetings on ANP program and receives briefing from Gen. Leslie Groves, Chief of Manhattan Engineering District.

March.—In a report to Congress, the Congressional Aviation Policy Board urges that program be accorded "the highest priority in atomic energy research and development * * *."

September.—Report prepared by Massachusetts Institute of Technology at request of AEC ("Lexington Report") predicted that a nuclear powered aircraft was feasible and could be achieved in about 15 years.

1949

Spring.—Ad Hoc Steering Committee for NEPA project established to provide program guidance, with representation from Air Force, Navy, AEC, and National Advisory Committee for Aeronautics.

November.—AEC begins ANP research project at Oak Ridge National Laboratory.

1950

March.—Aircraft Reactors Branch established in AEC and assumed responsibility for AEC part of NEPA project.

August.—Technical Advisory Board of Ad hoc Steering Committee reviews NEPA program and generally endorses it.

December.—Research and Development Board of Defense Department recommends program for development of subsonic aircraft for flight in 1956–57 period.

1951

February.—Air Force and AEC agree to close out NEPA project at Oak Ridge as general feasibility is indicated and research and development phase begins. It is decided to shift the program, under joint auspices, to the General Electric Co. for development of a propulsion plant.

February.—Air Force contracts with Convair Division of General Dynamics Corp. for application studies and initiates "flying testbed" program aimed at first flight in 1957.

February.—Joint Committee insists that Air Force support the ANP program on a scale sufficient to insure success or cancel it.

March.—Defense Department informs Joint Committee that Joint Chiefs of Staff have established official military requirement for construction of a nuclear

powerplant suitable for aircraft propulsion. Air Force Chief of Staff (General Vandenberg) urges AEC to give project high priority.

May.—NEPA project officially terminated and General Electric Co. initiates project aimed at development of a powerplant for eventual flight test. Direct cycle system is decided upon later in the year (October).

1952

April.—Air Force recommends to AEC development of nuclear propulsion system for flight test in subsonic aircraft in 1956–57 period.

May.—AEC approves use of part of National Reactor Testing Station at Arco, Idaho, as flight test base.

July.—AEC and Defense Department inform Joint Committee that plans are being made for flight test of a nuclear propulsion system in the 1956–58 period, utilizing a modified conventional plane as a "testbed" (B–36).

December.—Office for Aircraft Nuclear Propulsion is established to coordinate AEC and Air Force participation in the program, following suggestions by Joint Committee. Maj. Gen. Donald Keirn is named Director of the joint project, as Ad Hoc Steering Committee is phased out.

1953

March.—Ad Hoc Committee of Air Force Scientific Advisory Board recommends cutting ANP program back by 50 percent on grounds that activities are unwarranted by state of the art and rate of progress.

April.—National Security Council orders AEC and Defense Department cancellation of ANP program on grounds of budget savings and contention that program is not in the national interest. Secretary of Defense Wilson subsequently orders program canceled, terming nuclear plane a "shitepoke."

May.—Joint Committee calls urgent meeting to discuss the situation with Under Secretary of Defense Keyes and Secretary of Air Force Talbott. "Cancellation" of project is termed a misinterpretation of order and it is reported that reorganization of project is underway.

May.—The flying "testbed" program is terminated, together with most development on direct cycle propulsion system. Schedules for ground and fight test of propulsion system are indefinitely postponed. Program redirected toward applied research and development on a limited fund basis. Under this revised program a series of "High temperature reactor experiments" (HTRE's) were scheduled to develop and prove out the reactor powerplant.

December.—Air Force informs AEC of its renewed interest in manned nuclear aircraft and asks AEC to expedite experimental work.

1954

April.—General Keirn, Director of ANP project, tells Joint Committee that nuclear propelled aircraft could be in operation in as little as 50 percent of scheduled time, given a high priority.

May.—Joint Committee approves report by its Research and Development Subcommittee calling for a "crash" effort on the ANP project. Report is transmitted to the President, Secretary of Defense, and Chairman of Atomic Energy Commission.

July.—Joint Pratt & Whitney and Oak Ridge National Laboratory program established to develop indirect cycle propulsion system.

1955

February.—AEC reports that progress on direct cycle reactor has exceeded expectations and authorizes additional funds to be spent during the remainder of fiscal year 1955 in support of direct cycle program.

March.—Air Force issues requirement for high-performance, nuclear-powered aircraft weapons system. Testifies before Joint Committee, indicating that ground test of a prototype of the direct cycle system can be tested in about 1959.

April.—High-performance aircraft program initiated, with project office established at Wright Field. Competition for airframe studies is begun.

June.—AEC and Defense Department agree to accelerate ANP program with objective of testing prototype propulsion plant about 1959.

July.—Navy and AEC programs to develop nuclear plane integrated in AEC Aircraft Reactors Branch. Navy expresses interest in subsonic nuclear-powered seaplane.

September.—Test aircraft with small irradiation reactor aboard to test radiation effects and shielding was flown.

September.—Pratt & Whitney is authorized to perform work on indirect cycle reactor. Construction of CANEL (Connecticut Aircraft Nuclear Engine Laboratory) facility is started to accommodate anticipated expansion of ANP program.

November.—Navy requirement for nuclear seaplane is established and AEC assistance in developing propulsion system is requested.

November.—Air Force directs team-up of General Electric-Convair and Pratt & Whitney-Lockheed to proceed with propulsion systems for high-performance aircraft.

1956

January.—First "heater" experiment utilizing a direct cycle reactor with a turbojet engine is carried out successfully at Arco, Idaho.

April.—Navy proposal for "third approach" program is disapproved by Defense Department following recommendation by AEC that Navy should utilize efforts of two existing programs.

June.—Air Force Chief of Staff, General LeMay, tells Joint Committee he believes there is strong requirement for nuclear-powered aircraft. He expresses interest in achieving nuclear flight at earliest practicable date.

July.—General Keirn tells Joint Committee that ground test of a proplusion system is possible about 1959 and first flight about 1960.

August.—Revised fiscal 1957 program results in 18 months slippage in program schedule.

November.—Joint Committee informed of Defense Department policy decision to cut back ANP program.

December.—New reactor experiment operates successfully at Arco, Idaho and logs many hours of turbojet operation from nuclear heat.

December.—Accelerated program for high performance aircraft canceled following meeting of Defense Department and Budget Bureau officials with the President in Augusta. Direct cycle development continues on reduced basis; indirect cycle effort virtually eliminated. No specific objectives or target dates are retained.

1957

January.—Air Force Scientific Advisory Board reviews ANP program. Board recommends less emphasis on engine and airframe development, more on reactor research and development.

February.—Ad hoc committee of Defense Department ("Littlewood" Committee) begins review of ANP program.

February.—Joint Committee calls Defense Department and AEC officials to testify on status of program. Committee members urge that measures be taken to achieve early flight for nuclear aircraft prototype. Deputy Defense Secretary Quarles states that no flight date has been set, says none will be until propulsion system developed which is adequate for "useful" military plane.

February.—Air Force expansion of existing program to include low level subsonic plane.

February.—Ad hoc panel of General Officers (Mills panel) appointed in Defense Department to review ANP program and missions contemplated.

February.—Joint Committee sends letter to Secretary Quarles expressing concern about lack of firm program objectives and lack of centralized direction of program.

April.—Joint Committee urges Defense Department to proceed with vigorous ANP program and meets again with Secretary Quarles to emphasize its concern. Secretary Quarles testifies that program objectives have been established for ground and flight-test propulsion systems, looking toward first flight in the early 1960's.

April.—Littlewood Committee report is issued recommending, inter alia, that ANP development program should be carried through flight-test stage.

May.—Ad Hoc Evaluation Board of Air Research and Development Command issues report recommending development of low-level nuclear plane. (Canterbury Panel.)

May.—Budget Bureau sends directives to executive agencies, requiring that fiscal 1959 budget be held at same or lower level than fiscal 1958.

June.—Air Force Secretary Douglas sends letter to Joint Committee stating:

"We are convinced that early nuclear powered flight testing is an important part of the program. It is believed that accomplishment of actual nuclear flight will crystallize and clarify many of the problems concerning radiation hazards,

nuclear powerplant operation and maintenance and the actual capabilities of nuclear-powered aircraft."

June.—Mills report recommends that program objective should be early fabrication and flight testing of prototype propulsion system in the early 1960's. Report noted that problems of propulsion system could only be solved through actual test flight; favored test aircraft as immediate objective.

June.—Joint Committee is informed that procedures are being developed for unified project direction under General Keirn for better coordination of AEC and Defense Department activities.

June.—Navy proposes to Defense Department that nuclear turboprop plane concept be adopted.

June.—Joint Committee again meets with Secretary Quarles to discuss ANP and urge vigorous action on early flight.

July.—Secretary Quarles approves Air Force program looking toward first flight of experimental aircraft in mid-1960's.

September.—Budgetary ceilings cause slippage in time schedule for ground test and flight test of direct cycle system. It is recognized that under budget limitation, Pratt & Whitney effort on indirect cycle cannot be carried on as secondary effort at desired levels.

October.—Defense Department and AEC decide that high level group should be established to review hazards aspects of nuclear plane and make recommendations for national policy. Group is established (Hunsaker Committee) and begins review of program.

October.—Representative Price, chairman of Research and Development Subcommittee, after trip to Russia, sends letter to the President urging early flight program, both for military requirements and for psychological reasons, in light of Russia's success with sputnik. Letter expresses concern over lack of well-defined objectives and target dates.

November.—Proposals are made within Defense Department that a program looking toward early flight of a nuclear-propelled aircraft be instituted, utilizing a direct cycle propulsion system and a modified test aircraft as a flying testbed. No action is taken.

December.—Air Force advises Department of Defense of Air Force capability to demonstrate early flight in early 1960's.

December.—Navy advises Defense Department of Navy's intent to proceed with early flight program, utilizing modified seaplane with turboprop engines and direct cycle system. Navy says it is prepared to reprogram its own funds to carry out this objective.

December.—Hunsaker Committee report expresses concern over potential hazards of nuclear flight over land in development period and recommends first flights be made from island or coastal base. Joint Chiefs and service Secretaries, after review of report, express opinion that such action is premature.

1958

January.—AEC recommends to executive branch that early flight of nuclear plane should be pursued as means of increasing American scientific prestige in postsputnik era.

January.—President requests his science adviser, Dr. Killian, to review ANP program and Dr. Bacher is appointed chairman of study committee. Bacher group later is reconstituted as ad hoc advisory committee to the Deputy Secretary of Defense on the ANP program.

February.—Air Force makes strong recommendation to Defense Department on acceleration of early flight program aimed at achieving early flight in the early 1960's with direct cycle system.

February.—Bacher Committee recommends against accelerating early flight program with available materials and that greater emphasis be placed on more advanced materials capable of producing higher reactor performance.

February.—Following meeting with representatives of AEC, Defense Department, Dr. Killian and Dr. Bacher, President decides that accelerated flight program would detract from goal to achieve militarily useful aircraft and disapproves early flight proposals.

March.—President responds to Representative Price's letter of previous October. stating conviction that needs for development of a high performance military aircraft override early nuclear flight objective.

March.—Joint Committee meets with Secretary Quarles to discuss Bacher report on ANP program, including recommendations that plans for early flight be subordinated to increased emphasis on fundamental problems of research

and development. Joint Committee is informed that the President has approved Bacher report.

April.—Joint Committee is given Air Force and Navy briefing which was presented to Bacher Committee. General Keirn reiterates his confidence in direct air cycle system; expresses view new plane should be built for first flight rather than converted convential plane.

April.—Joint Committee calls members of Bacher Committee to testify on their report. Bacher Committee reiterates its belief that more fundamental research and development work needs to be done before decision is taken for first flight. Representative Price and some committee members indicate that Bacher Committee report is inadequate and not adequately based on firsthand review of work or reports.

June.—Strategic Air Command submits formal operating requirement for CAMAL aircraft (Continuous Airborne Missile Launching and Low-level Penetration System).

July.—Air Research and Development Command is authorized to initiate design-management competition for selection of airframe contractor by January 1, 1959.

October.—Air Force and Navy present proposals to Defense Department for flight program, and are asked to attempt to reach some common grounds to satisfy both requirements. Both services conclude that requirements are not compatible and therefore a common program is not possible.

November.—Defense Department agrees with AEC that ground test of propulsion system in about 1960 is desirable. Defense Department states that decision on plan for first flight has been deferred.

November.—Air Force and AEC present proposals to Secretary of Defense for accelerated early flight program, calling for reprograming of about $25 million in fiscal 1960 for each agency as added funds.

November.—Third experimental reactor in "heater" series at Arco begins power tests. Operating incident causes temporary shutdown.

December.—Following meeting with the President and Budget Bureau officials, decision is taken to cut back proposed AEC and Defense Department budgets to about $75 million each for fiscal year 1960.

1959

January.—Joint Committee receives testimony from Secretary of the Air Force, Secretary of the Navy, and Under Secretary of Defense Quarles on status of ANP program. Committee is informed that both Air Force and Navy have established requirements for nuclear-propelled aircraft. Air Force and AEC representatives state that both agencies have recommended reprograming an increase in their own 1960 funds for a flight program but proposals are not approved.

January.—General Keirn estimates that budget cutbacks will result in delay of about 1 year in achievement of a ground test prototype and confirms that no decision has yet been taken on flying program.

February.—Secretary Quarles briefs Joint Committee on program, reiterating position that until materials problems are solved, program would remain oriented toward development of nuclear propulsion system. Decision on nuclear flight would come later.

February.—Joint Committee announced scheduling of first public hearings on ANP program for mid-May.

March.—Convair selected in competition for airframe contractor.

April.—At Joint Committee suggestion, Secretary Quarles and Chairman McCone of AEC accompany members of the committee on personal inspection tour of General Electric project in Evendale, Ohio, for briefing on direct cycle propulsion system development.

May.—Consensus of meeting between representatives of Defense Department and AEC, including Secretary Quarles and Chairman McCone, is that draft recommendation should be prepared for submission to the President calling for an early flight program. Respective staffs are instructed to prepare such a draft recommendation.

May.—Following death of Secretary Quarles, Joint Committee postpones public hearings on ANP program.

May.—Joint Committee meets with Chairman McCone of AEC and Dr. Herbert York, Director of Defense Research and Engineering of the Department of Defense, to receive clarification on intention with regard to an early flight program. Committee members are promised a report the following month.

June.—Deputy Defense Secretary Gates, Dr. York, and Chairman McCone informed Joint Committee of decision to reorient ANP program toward development of more advanced materials and greater emphasis on indirect cycle approach. Committee is informed that decision will result in less work on materials for early flight program and that target dates for ground test prototype and nuclear flight have been eliminated. A delay of at least 2 years in achieving flight test prototype is admitted.

July.—Joint Committee announces rescheduling of public hearings on ANP program.

ANP Funding

TABLE I.—*ANP manned aircraft program summary, fiscal year 1946–fiscal year 1960—USAF-Navy-AEC*

[In millions]

Fiscal year	Operations	Facilities	Annual total	Cumulative total
1946	$1.3		$1.3	$1.3
1947	2.0		2.0	3.3
1948	6.2		6.2	9.5
1949	6.9		6.9	16.4
1950	6.7		6.7	23.1
1951	8.3	$0.5	8.8	31.9
1952	20.7	6.2	26.9	58.8
1953	40.6	18.6	59.2	118.0
1954	21.5	3.3	24.8	142.8
1955	46.8	7.1	53.9	196.7
1956	96.8	60.4	157.2	353.9
1957	141.0	45.0	186.0	539.9
1958	130.0	11.4	141.4	681.3
Subtotal	538.8	152.5	681.3	
1959 (estimated)	139.7	19.2	158.9	840.2
1960 (estimated)	143.4	7.0	150.4	990.6
Total	811.9	178.7	990.6	

TABLE 2.—*ANP manned aircraft program by agency, fiscal year 1946–fiscal year 1960*

[In millions]

Fiscal year	USAF		NAVY	AEC	
	Operations	Facilities	Operations	Operations	Facilities
1946	$1.3				
1947	2.0				
1948	6.2		[1] $1.0		
1949	6.9		[1] .5		
1950	5.3			$1.4	$0.5
1951	2.8			5.5	.5
1952	10.0	$6.0	[1] .5	10.7	.2
1953	22.6	6.3	.2	17.8	12.3
1954	6.2	.2	.1	15.2	3.1
1955	22.4	6.4	.5	23.9	.7
1956	46.4	57.4	3.7	46.7	3.0
1957	66.1	35.6	1.5	73.4	9.4
1958	60.5	2.4	2.9	66.6	9.0
Subtotal	258.7	114.3	8.9	261.2	38.2
1959 (estimate)	63.4	5.8	3.5	72.8	[2] 13.4
1960 (estimate)	68.0	7.0	2.0	[3] 73.4	
Total	390.1	127.1	14.4	407.4	51.6

[1] Navy funds transferred to Air Force which are included in the Air Force amounts. These amounts are not included in the Navy total.

[2] Based on current program planning, the total amount may not be placed under contract during fiscal year 1959.

[3] Excludes $0.3 of prefinancing.

APPENDIX B

PRESS RELEASES AND STATEMENTS

1959

No. 235

JULY 21, 1959.

From the Office of the Joint Committee on Atomic Energy.

A public hearing on progress of the aircraft nuclear propulsion program (ANP) has been scheduled for Thursday, July 23, it was announced today by Representative Melvin Price, chairman of the Subcommittee on Research and Development of the Joint Committee on Atomic Energy. In rescheduling the hearing, which was postponed earlier because of the death of Secretary Quarles, Representative Price made the following statement:

"We are distressed to learn that plans for a flight program for the nuclear propelled aircraft, which only 2 months ago appeared to be headed for high-level approval, are now being shelved in favor of a continuation of the present policy of drift and indecision which has characterized the aircraft nuclear propulsion program from its very inception.

"We have tried our level best to be patient in the hope that the Defense Department and the AEC would come to Congress with a firm program, looking toward flight testing of the direct cycle propulsion system which competent technical people, including the AEC's General Advisory Committee, are convinced is ready for proving out in actual flight.

"After 11 long years of discussing this matter in executive session with the Defense Department and the AEC, for reasons of national security, I believe the time has come for a public airing of this matter so that the American people can be better informed of the true facts of the situation.

"I am therefore scheduling public hearings for Thursday of this week in which we hope to bring out the major issues and questions involved. I believe that such hearings can be held without endangering the national security. On the contrary, I am convinced that the national security will, in fact, be enhanced by an informed public opinion."

Witnesses invited to testify at the hearings are: Maj. Gen. Donald Keirn, Director of the ANP project; Secretary of the Air Force Douglas; Gen. Thomas D. White, Chief of Staff of the Air Force; Secretary of the Navy Franke; Chairman McCone of the Atomic Energy Commission; Deputy Secretary of Defense Gates, and Dr. Herbert York, Director of Research and Engineering, Department of Defense.

The morning session of the hearings, beginning at 10 a.m., will be held in the Senate caucus room (room 318, Old Senate Office Building). The afternoon session, beginning at 2 p.m., will be held in the Old Supreme Court chamber of the Capitol (room P–63).

STATEMENT BY REPRESENTATIVE MELVIN PRICE, CHAIRMAN OF THE SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT, JOINT COMMISSION ON ATOMIC ENERGY, REGARDING SOVIET NUCLEAR PLANE PROGRAM, JANUARY 8, 1959

I think it would be misleading to state categorically that the Soviets are in fact flying a nuclear propelled plane at the present time.

On the other hand, I personally think there is a good possibility that the Soviets are well down the road in their nuclear plane program and have the capability of producing a flying nuclear-powered aircraft in the near future.

I think this underlines the importance of the United States pressing forward vigorously with its own ANP program. In particular, I think we have got to give our hardworking scientists and engineers the level of financial support they need to get the job done.

It is also vitally important to the success of our program that clear-cut objectives are established and the target dates for a ground test prototype and nuclear flight are set up as an effective guide to the program.

EXTRACT FROM TESTIMONY BY DEFENSE SECRETARY MCELROY ON FISCAL YEAR 1960 BUDGET BEFORE HOUSE TESTIMONY APPROPRIATIONS SUBCOMMITTEE, JANUARY 23, 1959

The nuclear powered aircraft project, because of the unusual amount of public attention it has received in recent weeks, deserves some special mention. This is

not a new project. The Department of Defense, jointly with the Atomic Energy Commission, has been working on the development of nuclear propulsion for aircraft for many years. Few people, however, realize the difficult technical problems involved in the development of a militarily useful aircraft of this type. It is not the airframe which presents the difficulty but rather the powerplant. To be militarily useful the propulsion system must have a high power density; that is, it must be powerful and compact and not unduly heavy. Moreover, adequate shielding must be provided to protect the crew and equipment against radiation hazards. In the present state of the art this would require a large and heavy airframe with low performance characteristics. Such an airplane, we believe, would have marginal military value in relation to other systems in operation, in production, or under development for the strategic mission.

We are not unaware of the psychological advantages which might accrue to the nation which first flies a true nuclear-powered aircraft. However, after the most thorough consideration of all the factors involved, it is still our judgment that this project should continue to be geared to valid technical and military considerations. The President has, therefore, included in his 1960 budget roughly $150 million, divided about equally between the Department of Defense and the Atomic Energy Commission, to carry out this objective. This is approximately the same amount available for the current fiscal year and brings our planned investment in the development of a nuclear-powered aircraft to the significant total of approximately $1 billion.

No. 189

JANUARY 7, 1959.

From the Office of the Joint Committee on Atomic Energy.

Representative Melvin Price, Democrat of Illinois, chairman of the Subcommittee on Research and Development of the Joint Committee on Atomic Energy, said today that the subcommittee will be briefed Thursday on Soviet progress in developing a nuclear-powered airplane. Representatives of the Air Force and Central Intelligence Agency will present the briefing at 10 a.m. in the committee room in the Capitol.

In commenting on the briefing, Representative Price said:

"Recent published reports claim that the Soviet Union has flight tested or is about to flight test a nuclear-powered plane. The Soviets themselves have lent credence to these reports in their recent public statements alluding to the progress they are making in the development of such a plane.

"We want to find out as much as we can of the Russian progress in order to evaluate it in relation to our own program. If the reports are indeed true, they indicate that the Soviets are well on their way to winning new laurels in their effort for technological superiority over the United States.

"We are holding the briefing at this early stage of the Congress to emphasize the importance of the United States being first in developing a nuclear-powered plane, both in terms of the national security and world confidence in America's scientific capabilities.

"The subcommittee intends to hold another hearing later this month to be brought up to date on the progress of our own aircraft nuclear propulsion program in this country."

No. 198

FEBRUARY 5, 1959.

From the Office of the Joint Committee on Atomic Energy.

STATEMENT BY MELVIN PRICE, CHAIRMAN, SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT, TOGETHER WITH CLINTON P. ANDERSON, CHAIRMAN, AND CARL T. DURHAM, VICE CHAIRMAN, JOINT COMMITTEE ON ATOMIC ENERGY, REGARDING HOLDUPS IN THE ANP PROGRAM

The following statement was issued today by Representative Melvin Price, chairman of the Subcommittee on Research and Development, together with Senator Clinton P. Anderson and Representative Carl T. Durham, chairman and

vice chairman of the Joint Committee on Atomic Energy, regarding holdups in the aircraft nuclear propulsion program (ANP) and the need for a greater level of support for the program:

"The Joint Committee's Subcommittee on Research and Development has concluded a series of detailed hearings on the current status and future prospects of the aircraft nuclear propulsion program. These hearings were held to determine what the present status of the ANP program is and to try to find out what, if any, concrete plans have been made for the future, directed toward the achievement of nuclear flight. Testimony was received from the Deputy Secretary of Defense, the Secretary of the Air Force, the Secretary of the Navy, members of the Atomic Energy Commission, and the Director of the project, General Keirn.

"The results of these hearings have left us gravely concerned, both from the point of view of our national security and from the standpoint of world confidence in America's scientific capabilities.

"After 12 long years of effort, during which time substantial technical progress has been made by our hardworking scientists and engineers in the field, we find this almost incredible situation:

"1. The program still has no firm set of objectives looking toward the development of a nuclear-propelled aircraft;

"2. No decision has been made regarding actual nuclear flight and no target dates have been set for such flight;

"3. Recommendations of the project director as to funding levels required to get the job done have been virtually ignored;

"4. It is authoritatively estimated that cuts in proposed funding levels for the program in fiscal 1960 will delay the achievement of a ground test prototype for an additional year and will thereby delay achievement of nuclear flight for at least that period of time;

"5. Administrative indecision at high levels and interservice rivalries have plagued the program from the start and have rendered a great disservice to the Nation;

"6. No less than seven advisory committees have been set up in the past decade to review the program, including the so-called Killian Committee, and yet the contractors in the field still have no clear guidance as to where they stand or where the program is going;

"7. The annual expenditure of $150 million for the ANP program as a holding operation to avoid difficult technical and administrative decisions which must be made to lend clearcut direction to the program is a completely indefensible use of the taxpayers' money;

"8. The Air Force and the Navy, after due consideration by their expert military advisers, have established firm requirements for nuclear-propelled aircraft. The Air Force and AEC both recommended an increase in their own fiscal 1960 budgets for the program to back up these requirements, but have been turned down.

"We have been informed that it is possible to have a flying prototype in the air by the summer or fall of 1962 if a target date is established immediately and if additional funding is provided now. Based upon our extensive review of the situation, we believe the establishment of such a target date and provision of additional funding are fully justified.

"The Joint Committee has been unwavering through the years in its active support of the ANP program. This support has transcended partisan lines and has been one of the bulwarks upon which the working engineers and scientists in the field have relied. We believe the time has come, in fact is long overdue, for a forthright statement on the part of the executive branch as to whether it intends to set a target date now for the successful achievement of nuclear flight or whether the taxpayer is going to be asked to continue to foot the bill for administrative indecision.

"We believe it is essential to decide, and decide now, on a program to achieve early nuclear flight. Any other course, in our view, is dangerous to the national security, wasteful of the taxpayers' dollar, and indefensible in the eyes of the American people."

DEPARTMENT OF DEFENSE

OFFICE OF PUBLIC INFORMATION

Washington, D.C.

News Release No. 135–59

FEBRUARY 6, 1959.

For the press:

Following is a statement by Deputy Secretary of Defense Donald A. Quarles on the aircraft nuclear propulsion program:

"At the end of a closed hearing in which associates and I presented to the Research and Development Subcommittee of the Joint Committee on Atomic Energy the administration's program for the development of aircraft nuclear propulsion (ANP), we were handed a mimeographed 'Immediate Release' statement by three members of the Joint Committee which attacked the administration's program as being 'a completely indefensible use of the taxpayer's money.' In his budget message last month, the President had this to say about the program:

" 'Work will also continue, at about the same level as in 1959, on the development of a nuclear powerplant for military aircraft. Until such a powerplant is successfully developed, and the technical problems involved in operating a nuclear-powered aircraft safely are solved, there is no practical military value in attempting to build the airplane itself. It is the judgment of my scientific advisers, which I approve, that the pace of this program should continue to be geared to valid technical considerations.'

"As brought out above and in the 'Immediate Release,' the ANP program proposed by the administration for fiscal year 1960 is at the fiscal year 1959 level of about $150 million a year. This is divided about equally between the Department of Defense and the Atomic Energy Commission.

"The basic issue is whether we should concentrate, as our program does, on the solution of the fundamental problems involved in creating a nuclear reactor of such compactness and efficiency as to be useful in a propulsion system for a military aircraft, or whether, in addition to this necessary basic work, we should have a so-called early flight program which would apply current technology and admittedly be too limited in operational characteristics to fulfill a useful military mission.

"The present program was adopted by the administration after most careful consideration of the fundamental scientific and technical problems involved. While there have been differences of opinion, most of the scientists and engineers who have been called in to review the program have advised that it would be unwise to undertake the early flight program until more progress had been made on the development of a reactor that would meet the military requirements.

"The present program gives high priority support to two alternative attacks on the fundamental propulsion problems. Progress along these fundamental lines, while impressive, has encountered substantial obstacles. It has been paced by science and technology rather than by funding.

"The allegation in the 'Immediate Release' that 'administrative indecision at high levels and interservice rivalries have plagued the program from the start' is, so far as I know, without foundation in fact. While the 10 or so years' history of this program has been marked by changes in course as the science and technology unfolded, timely administrative decisions have been and are being made. On best technical advice, they have been wisely made and in the national interest. Contrary to allegations, target dates for tests of ground prototypes have been established and were presented to the Joint Committee. Target dates for nuclear flight will be established as soon as there is a sound basis for doing so.

"That ANP is a strong, high priority program is evidenced by the decision of the administration to invest some $150 million a year in it. The program assumes that as soon as there is a valid basis for passing from the present propulsion development phase to a weapon system development phase, this will be done.

"As regards the allegation that the administration's program is a 'waste of the taxpayer's money,' there seems to be no question on the part of the Joint Committee that the whole program proposed by the administration should be carried out and that budgeted funds are properly applied to it. The 'Immediate Release' advocates an early flight program over and above the admin-

istration's program involving additional expenditures of the order of $50 to $100 million a year. The real question is not whether the present program is a waste of the taxpayer's money, but whether the added early flight program would involve such waste.

"It is conceded that the Soviets might choose the more spectacular early flight course. If they do so at this time by building a plane of such low flight performance as to be militarily useless, we can take some satisfaction in the fact that they will have wasted some of their resources."

No. 199

FEBRUARY 6, 1959.

From the Office of the Joint Committee on Atomic Energy.

Representative Melvin Price, Democrat of Illinois, chairman of the Research and Development Subcommittee of the Joint Committee on Atomic Energy, announced today that the subcommittee plans to hold public hearings within the next several weeks on the aircraft nuclear propulsion program (ANP), jointly managed by the Defense Department and Atomic Energy Commission.

Referring to a statement yesterday by Deputy Defense Secretary Quarles, that criticism by committee members of the conduct of the ANP program was intemperate and does great injustice to the program, Representative Price commented:

"If the Department of Defense feels that committee criticism of the conduct of the ANP program is unwarranted, I think the best course for us to follow is to lay the facts out on the table in a public hearing and let the chips fall where they may. For 10 long years the Joint Committee has been pressing the Defense Department and the Atomic Energy Commission to get on with the job of developing a flying prototype of a nuclear-powered aircraft and has urged time and again that difficult technical and administrative decisions be made so that the program can move forward vigorously.

"During this extended period the committee has respected the desires of the executive branch that our hearings on the ANP project be held behind closed doors because of the classified nature of the technical information presented.

"But if we are going to be charged with 'hitting below the belt' and misleading the public, I think it is high time the American public be given the opportunity to hear the true facts of the situation and make their own judgment as to who has been misleading whom for the past decade.

"I believe the basic facts can now be discussed without danger to the national security. In fact, I think the national security will be well served by public discussion of the program which has important implications for the national security and for world confidence in America's scientific capabilities."

An announcement will be made shortly on a date for the public hearings by the subcommittee and for the witnesses who will testify before the subcommittee.

No. 202

FEBRUARY 18, 1959.

From the Office of the Joint Committee on Atomic Energy.

STATEMENT BY REPRESENTATIVE MELVIN PRICE, DEMOCRAT, OF ILLINOIS, CHAIRMAN, RESEARCH AND DEVELOPMENT SUBCOMMITTEE, JOINT COMMITTEE ON ATOMIC ENERGY, PREPARED FOR DELIVERY IN THE HOUSE OF REPRESENTATIVES, FEBRUARY 18, 1959

Mr. Speaker, there has been a good deal of discussion in recent weeks about the importance of developing a nuclear-powered aircraft and the meaning of such an aircraft to the national security. My colleagues and I on the Joint Committee have been concerned for a number of years, as many of you know, about the administrative indecision and failure to set firm objectives which have plagued the ANP program from its inception.

One of our greatest concerns has been the demoralizing effect of this "on-again-off-again" approach in Washington on the devoted scientists and engineers in the field who are doing the actual research and development work. While these people have been making steady progress in their technical programs, they have constantly been frustrated by conflicting instructions over the years and by the lack of any clear guidance from Washington as to where the program

is going. Looking back over the last 10 years, it is a wonder that most of the topflight scientists and engineers in the project didn't leave in disgust.

One of these field experts has written me and several other members of the Joint Committee transmitting a copy of a letter he sent to the President on January 14—just a month ago—urging a more vigorous program in the interests of national security.

This man is a 7-year veteran of the General Electric project near Cincinnati where the major part of the work is going on to develop a nuclear powerplant for a military aircraft. In his covering letter to the President he said he was "speaking as a conscientious voting citizen who is sorely troubled by the trend of events," and expressed the hope that the President will "join those of us who are moved by a compelling faith and conviction that the (ANP) program is vital to the continued security of the United States."

Having received no response or acknowledgment from the White House to his letter, he has written me and several other members stating his conviction that if any corrective action is to be taken, the impetus must come from the legislative branch.

I believe that what this man has to say is important. While I don't necessarily subscribe to all his opinions, I think his statement accurately reflects the overriding conviction of our technical people in the field—the people who are actually bending the hardware—that this nuclear plane project has got to move forward more vigorously if we are to meet vital needs of national defense.

Speaking for his fellow scientists and engineers out on the firing line, he had this to say about the present state of technology in the project:

"The powerplant development work is now at a stage where it is ready to proceed at a faster pace. It is true that some solutions in 'detail' (as opposed to 'feasibility') are required—but these are the reasons why the development is necessary in the first place."

Then he goes on, and I quote:

"In today's environment, I get the impression that the only way to really get development support is to prove that everything is already comfortably in position—with all challenges answered in minute detail. In such a position, there will be development money made available—when, if such was really the case, the weapon should be in quantity manufacture."

He points out that:

"Today's situation on the nuclear-aircraft program is similar to that which prevailed on the missile programs 3 to 5 years ago. At that time, development work was accelerated on propulsion and guidance aspects of the work; today, we are just beginning to see signs that we will have operational missile systems over the next 2 to 4 years. The same situation can prevail for nuclear aircraft."

He follows this up by making this important point:

"The vacillator and the fence-sitter want to wait for the 1985 model although the 1959 model will still manage to outdistance anything on the road.

"It is my conviction, however—and I have lots of knowledgeable company—that failure to buy the 1959 model is not going to result in any improvement in what the 1985 model will do in its time.

"As a matter of fact, if we delay in facing up to the full-scale development of what can be done today—the 1985 capability won't come out until the year 2000—if ever."

Then he adds:

"Let's face it. Nuclear-powered aircraft are inevitable. The sooner we get about really facing up to the job in total—including an airframe—the sooner they are going to be a valuable weapon in our arsenal."

Referring to the administration of the program, he points out that the present manager of the ANP project, Maj. Gen. D. J. Keirn, has not received the necessary support and authority to do the job, regardless of various surface changes that have been made in the administration of the program. He then criticizes one of the admitted evils of the program, namely, the numerous advisory and review committees which over the years have virtually studied the program to death. He calls these committees aptly the "remote decision makers," which indeed they are because of their lack of comprehensive, firsthand experience with the work which is going on in the field.

"How," he asks, "a group of men can spend 2 to 4 hours at intervals of 18 to 24 months talking with the people who are doing the job and then say they have 'reviewed' the program is beyond my understanding."

Warning of Russian competence in the field of nuclear aircraft and emphasizing the imperative need for a U.S. retaliatory capability with low-level nuclear aircraft of unlimited range, he adds:

"In my opinion, the real danger lies in an underestimation of the American people. They are willing to pay more for national security * * *."

There is a good deal more thoughtful comment in the letter which this man has sent to the President which there is not time enough to describe here in full today. But I believe that the comments of this man are so important to a better understanding by the Congress and the public of the issues involved in our nuclear plane project—issues which are vital to the national security—that I believe the full text should be made available. I therefore ask that the full text be inserted in the record at this point.[1]

No. 208

MARCH 12, 1959.

From the Office of the Joint Committee on Atomic Energy.

Representative Melvin Price, chairman of the Research and Development Subcommittee of the Joint Committee on Atomic Energy, stated today that recent recommendations to the Secretary of Defense by Gen. Thomas D. White, Air Force Chief of Staff, calling for initiation of development work on an airframe for a nuclear powered aircraft and a step-up in work on the propulsion system for such an aircraft, are "further evidence" of the importance attached by military experts to accelerating the present aircraft nuclear propulsion program.

Referring to "reservations" which General White has communicated to Defense Secretary McElroy with regard to the Air Force fiscal 1960 budget, Representative Price stated:

"It is clear that General White and his expert military advisers in the Air Force believe strongly that the aircraft nuclear powered program (ANP) is important to the Nation's security interests and that the program is sufficiently advanced technically to warrant the commencement of work on an airframe and propulsion system suitable for first flight.

"The position which the Air Force Chief of Staff has taken underlines the necessity of getting on with the job of developing a ground test prototype propulsion system and making firm plans now for early nuclear flight, including the establishment of target dates.

"It also underlines the desirability, from an engineering standpoint, of proceeding with plans for actual flight testing of the propulsion system as a necessary first step toward eventual development of a fully operational military aircraft.

"The history of aeronatuical engineering has repeatedly demonstrated that such initial flight testing is not only useful; it is essential to the development of a combat-ready military aircraft.

"Further delay in taking this step will only serve to put off the day when such a combat-ready aircraft is ready to take its place in the Nation's defense system."

DEPARTMENT OF DEFENSE

OFFICE OF PUBLIC INFORMATION

Washington, D.C.

News Release No. 310–59

MARCH 20, 1959.

CONVAIR TO DESIGN AIRFRAME FOR NUCLEAR-POWERED AIRCRAFT

The Air Force announced today the selection of Convair Division of General Dynamics at Fort Worth, Tex., to work with the Nuclear Propulsion Division of the General Electric Co. in the initial design of a nuclear-powered bomber prototype.

Preliminary design studies have been conducted with two companies in the past, the Marietta Division of Lockheed Aircraft Corp. and Convair, Fort Worth. In recent months the design proposals of each of these companies have been carefully studied and the selection of Convair resulted from this evaluation.

Most of the current work on the aircraft nuclear propulsion program is concentrated on the development of the propulsion system. This will continue to

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[1] For text of letter, see p. 185.

be the case for the immediate future. However, it has been decided that more efficient use of the resources that are being invested can be realized if a single airplane company works directly with the propulsion contractor in carrying out the design from this point on.

The Air Force will continue to support limited design work at the Lockheed plant. Lockheed will also continue to operate the Georgia Nuclear Laboratory to conduct radiation effects experiments in support of the overall nuclear propulsion program.

APRIL 10, 1959.

CINCINNATI, OHIO.—A group of Government officials including the Honorable Donald A. Quarles, Deputy Secretary of Defense, Hon. John A. McCone, Chairman, Atomic Energy Commission, and the Honorable Melvin Price, chairman, Research and Development Subcommittee, Joint Congressional Committee on Atomic Energy, were briefed today by representatives of the General Electric Co. on the technical status of the GE aircraft nuclear propulsion department's project.

Others who received the briefing were Congressman James T. Van Zandt, of Pennsylvania, Congressman Craig Hosmer, of California, and Congressman William Bates, of Massachusetts, members of the Joint Committee; Commissioner John Floberg, of the Atomic Energy Commission, and Gen. Alvin Luedecke, AEC General Manager; Gen. Donald A. Keirn, director of the ANP project, and the Honorable Herbert Loper, chairman, Military Liaison Committee, Department of Defense.

In commenting on the briefing, Mr. Quarles, Mr. McCone, and Mr. Price made the following statement:

"We appreciate the fine technical presentations we have received today and the helpful and carefully planned tour of the GE facilities. We believe that this briefing has been very helpful as it is most important in reaching decisions in connection with this important program that we have current information on the project and the prospects for the future."

During the morning a comprehensive, detailed presentation was given to these officials on the reactor development portion of the program and they saw actual turbomachinery parts that are to be utilized. The visitors also toured the developmental laboratory and manufacturing facilities of the GE–ANP department.

Representatives of General Electric also outlined the relationship of the powerplant development work to the nuclear airframe studies program recently awarded to Convair Division of General Dynamics by the U.S. Air Force.

No. 225

MAY 3, 1959.

From the Office of the Joint Committee on Atomic Energy.

Representative Melvin Price, chairman of the Research and Development Subcommittee of the Joint Committee on Atomic Energy, announced today that the public hearings on the aircraft nuclear propulsion program, planned by the subcommittee for May 14 and 15, have been postponed because of the death of Deputy Defense Secretary Quarles.

In making the announcement, Representative Price stated:

"I am deeply shocked to hear of the untimely death of Dr. Quarles. Ever since he and I have known each other in Washington we have been close personal friends, despite occasional policy differences.

"Over the years I have known Dr. Quarles as a friend and a public official, he has time and again impressed me with his complete sincerity and forthrightness, his devotion to the welfare of this country and the time and energy he gave to the job of building our Nation's defenses.

"We shall miss him both as a friend and as a valued public servant."

No. 235

JULY 21, 1959.

From the Office of the Joint Committee on Atomic Energy.

A public hearing on progress of the aircraft nuclear propulsion program (ANP) has been scheduled for Thursday, July 23, it was announced today by Representative Melvin Price, chairman of the Subcommittee on Research and Develop-

ment of the Joint Committee on Atomic Energy. In rescheduling the hearing, which was postponed earlier because of the death of Secretary Quarles, Representative Price made the following statement:

"We are distressed to learn that plans for a flight program for the nuclear propelled aircraft, which only 2 months ago appeared to be headed for high level approval, are now being shelved in favor of a continuation of the present policy of drift and indecision which has characterized the aircraft nuclear propulsion program from its very inception.

"We have tried our level best to be patient in the hopes that the Defense Department and the AEC would come to Congress with a firm program, looking toward flight testing of the direct cycle propulsion system which competent technical people, including the AEC's General Advisory Committee, are convinced is ready for proving out in actual flight.

"After 11 long years of discussing this matter in executive session with the Defense Department and the AEC, for reasons of national security, I believe the time has come for a public airing of this matter so that the American people can be better informed of the true facts of the situation.

"I am therefore scheduling public hearings for Thursday of this week in which we hope to bring out the major issues and questions involved. I believe that such hearings can be held without endangering the national security. On the contrary, I am convinced that the national security will, in fact, be enhanced by an informed public opinion."

Witnesses invited to testify at the hearings are: Maj. Gen. Donald Keirn, director of the ANP project; Secretary of the Air Force Douglas; Gen. Thomas D. White, Chief of Staff of the Air Force; Secretary of the Navy Franke; Chairman McCone of the Atomic Energy Commission; Deputy Secretary of Defense Gates; and Dr. Herbert York, Director of Research and Engineering, Department of Defense.

The morning session of the hearings, beginning at 10 a.m., will be held in the Senate caucus room (room 318, Old Senate Office Building). The afternoon session, beginning at 2 p.m., will be held in the Old Supreme Court Chamber of the Capitol (room P–63).

(Copies of chronology and cost breakdown on ANP program are attached.) [1]

1958

JANUARY 7, 1958.

STATEMENT BY REPRESENTATIVE MELVIN PRICE, DEMOCRAT, OF ILLINOIS, CHAIRMAN OF THE SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT OF THE JOINT COMMITTEE ON ATOMIC ENERGY, ON THE AIRCRAFT NUCLEAR PROPULSION PROGRAM

For some years my colleagues and I on the Joint Committee on Atomic Energy have been gravely concerned over the indecision and lack of affirmative leadership which have characterized the conduct of the aircraft nuclear propulsion program. Since the very inception of the program, the committee has lent its full support to the project in the firm belief that early achievement of nuclear-powered flight is vital to the Nation's security interests and to world confidence in America's scientific capabilities.

On October 24, 1957, I wrote a letter to the President which I would like to read at this point:

"DEAR MR. PRESIDENT: Recent events including the launching of an earth satellite by the Soviet Union have lent urgency to the longstanding need for the United States to develop a flying capability in the field of nuclear-propelled aircraft. I feel the time has come, Mr. President, to make a direct appeal to you to lend the necessary initiative and support to our ANP program in the United States.

"Speaking frankly, Mr. President, the ANP program since its inception has suffered from a lack of incentive and initiative on the part of those who have been charged with the responsibility of conducting the program. It has also been characterized by the lack of any well-defined future objective, including target dates for completion, and has not had the kind of well-coordinated and centralized direction which is necessary for the successful achievement of such an extremely difficult research and development task.

"The Joint Committee on Atomic Energy has lent its full support to the ANP program from the beginning in the belief that it is vitally important to this Nation's security interest that we develop an operational capability in this field as

[1] See pp. 113–118.

soon as possible. Furthermore, we have felt that the achievement of the first nuclear-propelled aircraft, like the earth satellite, will have the most important significance in terms of world opinion.

"Several members of the Joint Committee and I have recently returned from a visit to the Soviet Union during which we had an opportunity to discuss various scientific matters with Soviet experts. I came away from these discussions convinced that the Soviets are placing considerable emphasis on their own program to develop a nuclear-propelled aircraft. I also became convinced that it is of paramount importance to the United States to produce such an aircraft first, not only from the standpoint of national security but from the point of view of world opinion and of world confidence in American scientific capabilities.

"It is for this reason that I am writing you directly to urge that you lend the full support of your office to the pursuit of a vigorous and effective program of nuclear aircraft development in this country to insure that the United States will in fact become the first nation to place a nuclear-propelled aircraft in the skies.

"Sincerely yours,

"MELVIN PRICE,
"Chairman, Research and Development Subcommittee."

In the weeks that followed there were encouraging signs that the long period of indecision and inaction were to be replaced by a more vigorous program aimed at the achievement of clearly defined objectives. Both the Atomic Energy Commission and the Air Force, who share primary responsibility for the conduct of the program, under the overall direction of General Keirn, appeared to be close to agreement on the scope and objectives of the program and recommendations for a definite program of action were being prepared for the President's approval.

But I have recently been advised that the Navy, which up until the present time has showed little interest in the program, now proposes to take over from the Air Force a large part of the administrative responsibility for aircraft and engine development. As a result of interservice rivalry and squabbling between the Air Force and Navy on this issue, the project has once again been thrown into a whirlpool of indecision and inaction, with the prospect of yet another study group being set up to referee the fight between the Air Force and the Navy.

I submit that the United States can ill afford, at this critical stage of world affairs, to indulge itself in senseless interservice squabbles whose principal effect is to delay the making of decisions which are vitally important to the continued momentum and vigor of our research program in the defense field.

This project to produce a nuclear airplane has almost literally been studied to death over the years of its existence. At last count I think there have been no less than six or seven expert panels and committees who have reviewed the project from time to time, some of them concurrently. The inference naturally arises that some of the study groups, at least, were established not so much for technical reappraisal as a device to permit top officials of the Defense Department to avoid their responsibility for making difficult but necessary decisions.

What this program needs is action, not another study group. It most urgently needs decision, not further delay. It needs courage at the topmost echelons of the Defense Department to decide upon a concrete course of action on the basis of ample available information. It requires, in essence, a willingness to make a clear and unequivocal recommendation to the President for a vigorous program aimed at the earliest achievement of a nuclear flight capability.

I believe it is clear, in this connection, that the most efficient and productive conduct of the program requires that those agencies who have shouldered the major burden and gained the greatest practical experience in the design and development work to date, namely, the Atomic Energy Commission and the Air Force, should continue with all due speed to the successful completion of their development programs. In the meantime the Navy, whose participation in the program has been relatively small in scale, should continue its important studies directed toward possible Naval uses for a nuclear aircraft.

In summary, we need decisive action and we need it now on the aircraft nuclear propulsion program. It is a time for firm decisions on the objectives we are aiming for and on the course we are to pursue in reaching those objectives.

The Soviet Union is pressing ahead with the development of its own nuclear powered airplane. I was told this personally by a leading Russian scientist during my visit to Moscow this past October with other members of the Joint Committee.

I think the United States must meet this challenge squarely and effectively, not only from the point of view of national security but also from the point of view of world opinion.

There is no doubt in my mind that the first nation to achieve actual nuclear flight will reap an enormous psychological victory as well as an important military advance. We lost on sputnik and with that loss went much of the worlds' confidence in America's scientific capabilities. We cannot afford another such loss without risking the gravest of consequences.

THE WHITE HOUSE, *Washington, March 5, 1958.*

Hon. MELVIN PRICE,
House of Representatives,
Washington, D.C.

DEAR MR. PRICE: I have understood that since you wrote to me respecting a nuclear powered aircraft, you have kept abreast of executive branch deliberations on this subject through consultations with my staff and with officials of the Defense Department and Atomic Energy Commission. I can now give you my decision on this program.

You mentioned two overriding objectives: First, earliest possible achievement of an operational military aircraft; second, making sure that America is the first nation to produce a nuclear powered aircraft, regardless of its utility, because of the possible worldwide significance of such an accomplishment.

I find no fault with either of these objectives, but unfortunately in present circumstances, they meet head on. If striving to be first were our shortest road to an operational military aircraft, we long ago would have pursued that course. But at the present state of the art such an effort would divert extremely scarce talent from attacking fundamental problems that must be solved before a militarily important aircraft can be produced. My conviction is that our need for the development of the high priority military aircraft overrides the first nuclear flight objective. Accordingly, I have decided that we should continue to go forward as rapidly as we effectively can with our development program, which at this stage places major emphasis on materials and reactor research, rather than to rush development of a first nuclear flight aircraft which would have little or no practical utility and would delay achievement of an effective military aircraft. We will continue, of course, to watch the developments in this field very closely and will capitalize to the greatest possible extent on such progress as is achieved.

You also stressed the need for well-defined future objectives and completion target dates. The development of a nuclear propelled aircraft capable of military missions has always been the prime goal of this program. This objective is clearly understood by all engaged on the project. Because the program requires development of new materials and techniques beyond the present state of knowledge, the specifying of dates for completion of these endeavors must be somewhat arbitrary and therefore may be unrealistic.

With warm regard,

Sincerely,

DWIGHT D. EISENHOWER.

STATEMENT BY DEPUTY SECRETARY OF DEFENSE DONALD A. QUARLES BEFORE THE RESEARCH AND DEVELOPMENT SUBCOMMITTEE, JOINT COMMITTEE ON ATOMIC ENERGY, IN THE MATTER OF AIRCRAFT NUCLEAR PROPULSION, THURSDAY, MARCH 6, 1958.

Mr. Chairman, in January of this year, General Loper and I appeared before several members of your subcommittee to explain where our aircraft nuclear propulsion program then stood. As I am sure you remember, we discussed a concept for the development of a manned nuclear propelled aircraft to be carried out jointly by the Atomic Energy Commission and the Department of Defense at a combined cost of about $150 million per year for the next several years.

This was a downward revision from the previous combined level of about $250 million per year, resulting from the decision to deemphasize the aircraft and weapon system aspect of the development at this time and to place primary emphasis on the research and fundamental development problems involved in advancing the atomic reactor art as applied to aircraft propulsion. We pointed out at that time that having in mind the very serious weight limitations as well as the severe requirements for minimizing radiation effects on the crew and other contents of the aircraft, the development of a useful nuclear propulsion system for manned aircraft calls for the solution of problems that are in some respects a hundredfold more difficult than those involved, for example, in the propulsion of heavy naval craft.

Jointly with the Atomic Energy Commission we have had for a number of years a large, high-priority program directed toward the solution of these problems. Recent reports by top-level scientific committees who have given careful study to the matter have led to the conclusion that we have still not reached a state of the art that will permit the application of nuclear propulsion to the design of a military aircraft that will satisfactorily perform the high-priority mission toward which this line of development has been primarily directed.

At the January meeting, we discussed the possibility of a program for the development of a nuclear propelled manned aircraft that would demonstrate nuclear flight at an early date, even though it might fall far short of military objectives for a combat aircraft. It was thought at that time that such an early flight development might contribute significantly to the military objective by giving us experience with the operation of such an aircraft. We were also conscious of the fact that the Soviets may well be working on similar developments and that they might seek to obtain propaganda value by demonstrating manned nuclear aircraft flight even though in doing so they abandoned military utility as an objective.

In light of the best advice of scientists and engineers specializing in this field, we have come to the conclusion that such an early flight program would tend to divert all-too-scarce talent from the main military objective and that any early flight aircraft that could now be designed and produced would have such marginal operational characteristics as to be without value to the program even for the purpose of providing operational experience. In reaching this conclusion, we have been mindful of the radiation hazards involved in such operation, as well as of the more straightforward engineering and design problems.

The program which we are now presenting to your committee is therefore substantially the program we discussed earlier this year. It emphasizes the basic work that needs to be done on higher temperature materials and other reactor design problems to achieve reactors that can operate at higher temperatures and therefore produce higher thrust with a lower weight encumbrance on the aircraft and a lower radiation hazard to the crew. Jointly with the Atomic Energy Commission, we are pursuing this work along two parallel lines involving different reactor principles and we are paralleling the reactor studies with studies of turbojet and turboprop engines and the special instrumentation that might be associated with the reactors in useful military aircraft designs. We are also supporting these component studies with such aircraft design studies as are required to make the work on the components meaningful.

As for the "cold war" significance of first nuclear flight, the committee will recall that several years ago we actually flew an operating nuclear reactor in a military aircraft without, however, attempting to use the power for propulsion purposes. We have also, of course, demonstrated the use of nuclear reactors as a source of power for driving more or less conventional aircraft jet engines in ground tests. To combine these in a first-flight demonstration would not be an important addition to what has already been done. Moreover, it would not only add substantially to the cost of the project, but it would divert specialized talent in a way which might delay the final achievement of the objective. In arriving at this view, we are quite conscious of the fact that the Soviets may adopt a different view and may seek to make propaganda capital out of a different course of action.

The program just outlined is well suported by the technical evidence. We, of course, must recognize that this is a fast-moving art and that the fundamental development work that is being carried on might well uncover practical possibilities not now visualized. We will continue to be on the alert for such possibilities and will, of course, want to propose a change in this course and perhaps

an accelerated program of development and flight test if and when the feasibility of such an accelerated program can be established.

In this connection, I should point out that both the Air Force and the Navy have requirements for a nuclear-propelled aircraft and that there are substantial differences between the two services as to the characteristics that would best serve their purposes. Most of what I have said above relates particularly to the needs of the Air Force program. The Navy is now pursuing a somewhat different approach that offers promise of meeting its special requirements. We expect that it will be some months before the results of these Navy studies will be available. We also anticipate that at that time there will be further significant results from reactor development work now underway. We propose at that time to reevaluate the whole situation in the light of all the facts available and will report our conclusions to your committee, including any changes that we might then propose to the program we have outlined above.

MARCH 6, 1958.

From the Office of the Joint Committee on Atomic Energy.

JOINT STATEMENT BY REPRESENTATIVE CARL T. DURHAM, CHAIRMAN OF THE JOINT COMMITTEE ON ATOMIC ENERGY, AND REPRESENTATIVE MELVIN PRICE, CHAIRMAN OF THE SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT, REGARDING THE AIRCRAFT NUCLEAR PROPULSION PROGRAM

It is clear that the administration's decision to abandon the concept of achieving a nuclear flight capability at the earliest moment constitutes a serious setback to our aircraft nuclear propulsion program. It opens the door wide to the prospect that the Russians will once again administer a humiliating defeat to the United States by placing the first nuclear-powered aircraft in the skies. Coming on the heels of the sputnik fiasco, a Russian victory in this field could well prove disastrous to world confidence in America's scientific abilities.

We had been led to believe, until very recently, that the longstanding inaction and indecision which have characterized the conduct of the ANP program since its inception would be replaced by a vigorous and well coordinated program aimed at an early flight capability. A concrete plan of action to achieve this important first step was prepared within the Defense Department after sputnik on the basis of the best expert advice available and had been submitted to the Secretary and Deputy Secretary of Defense for their approval, prior to submission of the Defense Department's recommendations to the President.

At this point the Killian Committee stepped into the picture to "expedite" matters. An advisory group set up by Dr. Killian proceeded to make a cursory review of the program and after a brief inspection trip to the field, returned with recommendations that the early flight concept with a modified conventional plane be scrapped in favor of a vague development program aimed at the ultimate achievement of a high performance craft. Little or no account was taken, apparently, of the obvious psychological importance, in terms of world opinion, of our producing the first nuclear-powered aircraft before the Soviets.

The recommendations of the Killan Committee were passed along to the President, oddly enough, before he had received the Defense Department recommendations. In the interim, the Killian advisory panel was reconstituted as an advisory group to the Pentagon. We now find that the end result of all this "expediting" has been to slow down rather than accelerate the program and that we are actually wore off today in terms of our objectives than we were a year ago, before sputnik. This situation is patently ridiculous and raises the gravest doubt as to whether the United States can effectively respond to the Soviet challenge.

Members of the Joint Committee have always recognized and continue to recognize that very difficult technical problems confront the scientists and engineers in the field who are doing the actual developmental work in the ANP program. We do not hold ourselves out as technical experts but we have followed the program closely over the years and have been impressed during our trips to field installations with the very substantial progress which has been achieved in overcoming these technical problems and in meeting goals. We have consistently given our strong support to this project in the belief that it is vitally important to the national interest. The record shows that similar strong support from the Joint Committee was instrumental in the development of the hydrogen

bomb and the atomic submarine, both of which now stand as bulwarks of our Nation's defense and are among the strongest deterrents we possess against aggression.

We have no illusions about the magnitude of the task ahead nor about the many tough technical hurdles which still must be submounted. But we firmly believe, as we have over the years, that progress can be achieved and will be achieved when we have a concrete program with clear objectives and target dates for completion, up to and including a proven flight capability. Without such goals, there can only be a hopeless, hapless, and helpless policy of drift and indecision.

This is where we have been for the last 10 years, and this is where we stand today. No amount of rationalization can hide this fact and we think the record should be very clear as to where the responsibility lies for this sorry state of affairs, namely, in the executive branch.

No. 128

March 7, 1958.

From the Office of the Joint Committee on Atomic Energy.

Representative Melvin Price, Democrat, of Illinois, chairman of the Research and Development Subcommittee of the Joint Committee on Atomic Energy, today charged that the administration's claim that development of an early flying nuclear-powered aircraft would waste scientific manpower is a "smoke screen for inaction" and "without basis in fact."

He was commenting on the testimony presented to the subcommittee yesterday by Deputy Defense Secretary Quarles together with a letter he received from the President yesterday regarding the administration's decision to slow down the aircraft nuclear-propulsion program.

"I have been informed categorically by the people actually working on the project," he said, "that far from wasting manpower, the development of an early flying nuclear plane would in fact be the best possible utilization of existing scientific and engineering talent and would serve as a strong incentive for them to get on with the job. It was clearly brought out during the testimony, in response to the committee's questions, that an adequate supply of such talent exists not only for present needs but for an accelerated program as well."

Referring to statements by the President and Secretary Quarles that the development of an early flying aircraft would have little or no utility and would delay achievement of a high performance military plane, Representative Price stated:

"I believe the exact opposite to be true. The history of research and development is replete with examples, such as the hydrogen bomb, which demonstrate beyond argument that successive stages of development are necessary before the finished product can be achieved and that actual operating experience is essential to test out experimental devices. Such operating experience serves as an impetus, not a deterrent, to the achievement of our ultimate objectives.

"It is evident," he went on, "that there is a delay involved here, but the delay is in the administration's timetable for an operational plane. This is indeed paradoxical in light of the Soviet challenge and appears to indicate that there has been no change in the administration's attitude since sputnik.

"I would like to reiterate," he added, "that it is vitally important to America's security interests and prestige that we place a nuclear-powered aircraft in the skies before the Russians. If we continue to drag our feet, we may soon be faced with another shattering blow to world confidence in America's scientific capabilities."

Joint Committee on Atomic Energy

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

Meeting on Aircraft Nuclear Propulsion Program, Friday, April 25, 1958

Opening Remarks by Representative Melvin Price, Chairman of the Subcommittee

The Subcommittee on Research and Development is meeting this afternoon to discuss the "Report of the Ad Hoc Advisory Committee to the Deputy Secretary of Defense on the Aircraft Nuclear Propulsion Program," whose Chairman is

Dr. Robert F. Bacher. Dr. Bacher, we are glad to have you and your associates on the Ad Hoc Committee with us today to assist in the discussions on your report.

Before we start, I would like to reiterate the longstanding interest of the Joint Committee in the ANP program which has received the Committee's wholehearted support since its inception 11 years ago. We have strongly believed in the past and we continue to believe today that the development of a nuclear-powered aircraft by the United States is essential to our Nation's security interests and to world confidence in America's scientific abilities.

The shattering impact of Russia's sputniks last fall served to underline the importance to the United States and the rest of the free world of achieving a nuclear flight capability at the earliest possible time, before the Soviets. It became evident that we could ill afford another humiliating psychological defeat in the eyes of the world. Our views were reinforced by our talks with Russian scientists in Moscow last fall who confirmed that the Soviets were indeed pursuing a vigorous development program for a nuclear-powered aircraft.

On our return we were therefore gratified to hear from Deputy Defense Secretary Quarles, in his appearance before this Committee last January, that consideration was being given to an accelerated program aimed at the development of an early flight nuclear aircraft. From all indications, the Defense Department was on the verge of approving such an accelerated program and sending recommendations to this effect to the President.

Then, on short notice, there was a shift in attitude and the program was once again subjected to an air of indecision and confusion. This Committee attempted on two separate occasions to schedule meetings with representatives of the Defense Department to seek information on the situation and twice acceded to requests for postponement by the Defense Department to allow the executive branch to prepare itself better for a useful presentation.

During this period of indecision and delay the Committee was informed that Defense Department recommendations to the President were being held up pending a review of the program by an advisory committee appointed by Dr. Killian and that no action would be taken until completion of this review. It is my understanding that you gentlemen here today were members of this original advisory committee to Dr. Killian and that you were later reconstituted as an ad hoc advisory group to the Deputy Secretary of Defense following your report to Dr. Killian. It is in this latter capacity that we have invited you here today to discuss your report.

I think it is only fair to state at this point that some of us on the Joint Committee who have lent our support to the ANP program over the years of its existence were greatly disappointed that the Ad Hoc Committee in its report recommended against an accelerated program aimed at an early flight aircraft. I think all of us around the table today have the highest regard for you, Dr. Bacher, and for your associates who served with you on the Ad Hoc Committee. You are all men of outstanding ability and reputation.

What concerns some of us is that many of the conclusions you reached in your report are directly at variance with testimony which the Committee has received from the major contractor in the program and from the responsible representatives of the Atomic Energy Commission. It is these differences of opinion which we would like to try to reconcile here today.

Dr. Bacher, as Chairman of the Ad Hoc Committee, you may have a few words which you wish to say before we start discussions on the report itself. We wish to welcome you back to Washington after your several years of absence. We are glad to see you again. Would you please proceed.

No. 183

DECEMBER 1, 1958.

From the Office of the Joint Committee on Atomic Energy.

Representative Melvin Price (Democrat, Illinois), chairman of the Research and Development Subcommittee of the Joint Committee on Atomic Energy, today renewed his call for prompt and decisive action by the administration in accelerating the U.S. program for the development of a nuclear-powered aircraft.

Referring to recently published reports that the Soviets have successfully flown an aircraft propelled by nuclear energy, Representative Price stated:

"We have reached a critical stage in our nuclear aircraft program (ANP). Either we push forward vigorously to a successful conclusion of our efforts or we forfeit, once again, our technological leadership.

"The history of the ANP program is replete with examples of indecision, indifference, and ineffectiveness which have plagued the program from the start. It is indeed ironic that while the scientists and engineers actually working on the project in the field have consistently moved forward toward achievement of their technical objectives, they have just as consistently had the rug pulled out from under them by bureaucratic snafus in Washington.

"There is a limit beyond which even the most dedicated people in the field cannot be expected to go in their efforts to maintain America's scientific leadership. We have reached that limit.

"I am informed that a policy-level meeting is to take place in the near future within the administration to discuss acceleration of the ANP program. It is essential, not only to the national interest, but to the morale of our working scientists and engineers in the field, that a clearcut decision be made at this time as to the objectives of the program. This decision should include target dates for a ground test of the prototype and for the first flight.

"The Nation can ill afford further delay and indecision. The time for further rationalization has long since passed. The administration can—and must—come out from behind the protective shelter of study committees and panels and establish the well-defined objectives necessary for a vigorous and effective development program.

"The Joint Committee, as yet, has received no new information on the extent of the Soviet success in their nuclear aircraft program. However, their objective of nuclear-powered flight has been known for some time. More than a year ago, my own discussions with Soviet officials during a trip to Russia confirmed their great interest in powering an airplane with nuclear energy. When I returned to this country, I wrote President Eisenhower about the ANP program, pointing out the importance of our being first with the atomic plane, especially in view of Soviet satellite launching success."

(Attached is the correspondence exchanged between Representative Price and President Eisenhower concerning the progress of the program.)

CONGRESS OF THE UNITED STATES,
JOINT COMMITTEE ON ATOMIC ENERGY,
October 24, 1957.

THE PRESIDENT,
The White House.

DEAR MR. PRESIDENT: Recent events including the launching of an earth satellite by the Soviet Union have lent urgency to the long-standing need for the United States to develop a flying capability in the field of nuclear propelled aircraft. I feel the time has come, Mr. President, to make a direct appeal to you to lend the necessary initiative and support to our ANP program in the United States.

Speaking frankly, Mr. President, the ANP program since its inception has suffered from a lack of incentive and initiative on the part of those who have been charged with the responsibility of conducting the program. It has also been characterized by the lack of any well-defined future objective, including target dates for completion, and has not had the kind of well coordinated and centralized direction which is necessary for the successful achievement of such an extremely difficult research and development task.

The Joint Committee on Atomic Energy has lent its full support to the ANP program from the beginning in the belief that it is vitally important to this Nation's security interest that we develop an operational capability in this field as soon as possible. Furthermore, we have felt that the achievement of the first nuclear propelled aircraft, like the earth satellite, will have the most important significance in terms of world opinion.

Several members of the Joint Committee and I have recently returned from a visit to the Soviet Union during which we had an opportunity to discuss various scientific matters with Soviet experts. I came away from these discussions convinced that the Soviets are placing considerable emphasis on their own program

to develop a nuclear propelled aircraft. I also became convinced that it is of paramount importance to the United States to produce such an aircraft first, not only from the standpoint of national security but from the point of view of world opinion and of world confidence in American scientific capabilities.

It is for this reason that I am writing you directly to urge that you lend the full support of your office to the pursuit of a vigorous and effective program of nuclear aircraft development in this country to insure that the United States will in fact become the first nation to place a nuclear propelled aircraft in the skies.

Sincerely yours,

MELVIN PRICE,
Chairman, Research and Development Subcommittee.

THE WHITE HOUSE,
Washington, March 5, 1958.

HON. MELVIN PRICE,
House of Representatives,
Washington, D.C.

DEAR MR. PRICE: I have understood that since you wrote to me respecting a nuclear powered aircraft, you have kept abreast of executive branch deliberations on this subject through consultations with my staff and with officials of the Defense Department and Atomic Energy Commission. I can now give you my decision on this program.

You mention two overriding objectives: first, earliest possible achievement of an operational military aircraft; second, making sure that America is the first nation to produce a nuclear powered aircraft, regardless of its utility, because of the possible worldwide significance of such an accomplishment.

I find no fault with either of these objectives, but unfortunately in present circumstances, they meet head on. If striving to be first were our shortest road to an operational military aircraft, we long ago would have pursued that course. But at the present state of the art such an effort would divert extremely scarce talent from attacking fundamental problems that must be solved before a militarily important aircraft can be produced. My conviction is that our need for the development of the high priority military aircraft overrides the first nuclear flight objective. Accordingly, I have decided that we should continue to go forward as rapidly as we effectively can with our development program, which at this stage places major emphasis on materials and reactor research, rather than to rush development of a first nuclear flight aircraft which would have little or no practical utility and would delay achievement of an effective military aircraft. We will continue, of course, to watch the developments in this field very closely and will capitalize to the greatest possible extent on such progress as is achieved.

You also stressed the need for well-defined future objectives and completion target dates. The development of a nuclear propelled aircraft capable of military missions has always been the prime goal of this program. This objective is clearly understood by all engaged on the project. Because the program requires development of new materials and techniques beyond the present state of knowledge, the specifying of dates for completion of these endeavors must be somewhat arbitrary and therefore may be unrealistic.

With warm regard.

Sincerely,

DWIGHT D. EISENHOWER.

EXCERPTS FROM SENATOR RUSSELL'S TV STATEMENT ON THE ANP PROGRAM
DECEMBER 1, 1958

The report that the Russians have test flown an atomic-powered aircraft is an ominous new threat to world peace and yet another blow to the prestige and security of our Nation and the free world.

It follows in tragic sequence the Russian success of last fall in launching the first earth satellite. If the report is true, it means that we are today faced with a new weapon of terrifying consequences. A plane powered by nuclear energy could have practically unlimited range and load capacity and, therefore, would be a weapon of incalculable danger to us.

The Russians may or may not choose to make the most of the military implications of their potential new weapon. But they are certain to make the most of the psychological advantage of being the first to harness nuclear power for flight. The report, if true, means that the West once again has been outstripped by Soviet technology.

This development points up what I have said time and time again: that we have consistently underestimated the productive capacity of Communist Russia. Before the Senate Committee on Armed Services, I have reminded administration officials that the Russians built and successfully flew aircraft over the North Pole and into this country as far back as the early 1930's.

The Eisenhower administration must shoulder the blame for this latest defeat of the West in the technological field by Russia.

I and other members of the Armed Services Committee have for many years urged officials of the executive branch to put greater emphasis on development of missiles and similar weapons. Congress has given the administration all of the legislative authority and money requested in the field of missile research and development. And many of us have criticized sharply the cutbacks imposed by the Executive in this all-important field as well as general reductions in our overall military strength.

But despite our efforts and our protests, the administration has trimmed our Defense Establishment to meet the wishes of the Treasury Department and the Budget Bureau.

Now, once again, we have seen the tragic consequences of this unbelievably shortsighted policy. The prices of this policy must be reckoned in the increased danger to our national security and to our very existence.

In October of last year, following the launching of the first Russian sputnik, I declared that we could restore the damage to our world prestige by being the first to produce an atomic-powered aircraft.

However, the Department of Defense, over my protests, foolishly cut the program during the last fiscal year by two-thirds. Not being satisfied with that, they cut it still further during the current fiscal year and, as a result, we are now spending less on the atomic aircraft program than we were 3 years ago.

During this period, I had time and again urged former Secretary of Defense Wilson to expedite this far-reaching program.

The development of an atomic-powered aircraft has even greater implications than powering a bomber by nuclear energy. It is an important step in the development of an atomic-powered missile.

Though we have apparently once again been beaten by Russian technology, I hope the administration will now proceed full speed with the development of an American atomic-propelled aircraft. It doubtless will do so on a crash basis which is bound to be wasteful in terms of dollars and scientific effort.

This points up once again the need for an orderly, long-range policy of defense planning so vital to the survival of the United States and the free world.

1957

No. 72

MARCH 4, 1957.

From the Office of the Joint Committee on Atomic Energy.

Two ranking members of the Joint Committee on Atomic Energy today told the House of Representatives that they are becoming increasingly concerned over the tendency on the part of Secretary Wilson and the Department of Defense to deemphasize research and development work in connection with our national defense program. They pointed particularly to the adverse effect which this negative approach toward research and development is having on the aircraft nuclear propulsion program.

Congressman Carl Durham, (Democrat, North Carolina) chairman of the Joint Committee, spoke out against plans to consolidate military research development, and engineering under the central direction of the former Assistant Secretary of Defense for Applied Engineering. He noted that such an arrangement implied an intention to lay greater stress on the so-called practical applications of technology and relegate basic research and engineering development to a relatively minor role.

"Nothing could be more foolhardy in the long-term national interest," he said, "for all progress in the practical applications of military technology is vitally dependent on underlying experience gained from fundamental research and preliminary development work."

"I think it is essential," he added, "that our military research and development program be headed up by a topflight individual having the confidence of the scientific community, with a staff composed of imaginative and dedicated men who are unafraid to explore new scientific frontiers."

In commenting on a statement by Secretary Wilson that "a miracle or two" will be necessary to produce a militarily useful nuclear-powered aircraft, Representative Durham noted that the technical part of the program being done by the contractors in the field is progressing well.

Strongly endorsing Mr. Durham's views, Representative Melvin Price (Democrat, Illinois) chairman of the Joint Committee's Research and Development Subcommittee, said he had personally visited the contractor installations where developmental work is being done on the nuclear-powered aircraft and that he could say without hesitation that technical progress is good.

"The main difficulty," he said, "appears to be in the Pentagon where administrative confusion and indecision over research and development objectives have marked the conduct of the ANP program for the past year."

"This situation," he continued, "raises the serious question as to whether there should be a major reorganization of the present administrative machinery governing the ANP program and the appointment of an administrator with sufficient authority to see that the job gets done."

He then added:

"Development of the nuclear-powered aircraft is a matter of high priority in the national defense interest and should be pursued with all vigor. If the Department of Defense and the Atomic Energy Commission will not or cannot do the job, there is no alternative for the Congress but to find some organization which can."

Statement by Mr. Durham in the House of Representatives, March 4, 1957

Mr. Speaker, over the past several years I have noted with increasing concern the tendency on the part of Secretary Wilson and the Department of Defense to deemphasize research and development work in connection with our national defense program. I hardly need point out that a vigorous research and development program utilizing the best scientific talent available is indispensable to the maintenance of military superiority in an era of rapid technologcal advances and change.

The most recent and, in a sense, most alarming manifestation of this tendency toward deemphasis on basic research has been the announcement by the Pentagon of plans to consolidate military research, development, and engineering under the direction of the former Assistant Secretary of Defense for Applied Engineering. The idea, apparently, is to lay greater stress on so-called practical applications of technology and relegate basic research and engineering development to a relatively minor role. Nothing could be more foolhardy in the long-term national interest. For all progress in the practical applications of military technology is vitally dependent on underlying experience gained from fundamental research and preliminary development work.

With all due respect to the engineering profession which has contributed so much to our Nation's strength and security, I think it is essential that our military research and development program be headed up by a topflight individual having the confidence of the scientific community, with a staff composed of imaginative and dedicated men who are unafraid to explore new scientific frontiers. There is no such thing as the status quo in military technology. You either progress or you fall behind. And the only means of insuring progress is through a vigorous research and development program aimed at developing new ideas and concepts on a continuing basis.

Secretary Wilson has been quoted by the press as stating that he is not downgrading research, but that military research funds should be concentrated on developing promising projects, leaving spending on long-range fundamental research to others. This might aptly be called the let-George-do-it approach to military security.

A classic example of the adverse effects of this philosophy on our national defense effort may be found in the case of the aircraft nuclear propulsion program which, for the past year, has been plagued by indecision and inaction at high levels in the Defense Department, to the serious detriment of the entire program. Secretary Wilson has been further quoted as stating that "a miracle of two" will be necessary before the United States can build a nuclear-powered air-

craft suitable for use by the military. As a longtime member of the Joint Committee on Atomic Energy which has studied and energetically encouraged the aircraft nuclear propulsion program since its inception, I can say that the technical part of the program being done by the contractors in the field is progressing well.

STATEMENT BY MR. PRICE IN THE HOUSE OF REPRESENTATIVES, MARCH 4, 1957

Mr. Speaker, I heartily endorse the comments made by my distinguished colleague, Mr. Durham. It is indeed ironic that at a time when military technology is advancing at an unprecedented rate and when our very survival may depend on staying ahead in the field of technology, Secretary Wilson has chosen to relegate research and development to a secondary role in the Defense Establishment. Not only that, but he has apparently amalgamated the research and development function with the applied engineering function, thereby stifling the effectiveness of both.

Like my colleague, Mr. Durham, I have the greatest respect for the engineering profession but I submit that it just doesn't make sense to place the former Assistant Secretary of Defense for Applied Engineering, Mr. Newbury, in charge of research and development activities. If we are to maintain our lead in military technology, the first requirement is to have an independent research and development staff, made up of the best scientific brains we can get. This group must be free to encourage exploration of new ideas and reject outdated concepts, where necessary. Most important, this group must have vigorous leadership which isn't afraid to venture into uncharted fields of technology.

I would like particularly to commend my colleague, Mr. Durham, for his comments on the aircraft nuclear-propulsion program and on how the Pentagon's increasingly negative approach toward research and development has thwarted progress in this field. After careful study of this program and a personal visit to the contractor installations where the actual developmental work is being done, I can say without hesitation that technical progress is good. The main difficulty appears to be in the Pentagon where administrative confusion and indecision over research and development objectives have marked the conduct of the program for the past year. This is a sad commentary on a program which is of such vital interest to the country's future security.

This situation raises the serious question as to whether there should be a major reorganization of the present administrative machinery governing the ANP program and the appointment of an administrator with sufficient authority to see that the job gets done. This administrator might occupy a position similar to that of Adm. H. G. Rickover, who directs the naval propulsion program which produced the *Nautilus*.

Development of the nuclear-powered aircraft is a matter of high priority in the national defense interest and should be pursued with all vigor. If the Department of Defense and the Atomic Energy Commission will not or cannot do the job, there is no alternative for the Congress but to find some organization which can.

ATOMIC ENERGY COMMISSION,
Washington, D.C., November 21, 1957.

HON. CARL T. DURHAM,
Chairman, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. DURHAM: The Department of Defense and the Atomic Energy Commission have established an integrated project office to manage their joint program leading to the application of nuclear power for the propulsion of aircraft and missiles. As in the past the Atomic Energy Commission will be responsible for the development of reactors while the Air Force will carry on engine development and other related works. The new organization will provide the executive management for the entire program involving nuclear flight systems and will call on subordinate organizations where neded for support in specific areas. The Department of the Navy will also particpate in this program and will be represented in the organiaztion.

By the terms of the agreement between the Air Force and the Atomic Energy Commission which establishes this office, Maj. Gen. Donald J. Keirn, USAF, has been selected as office head with responsibility for all work in connection with

nuclear propulsion systems for aircraft and missiles, both in the Air Force and the Atomic Energy Commission. General Keirn continues in his assignment as Chief of the Aircraft Reactors Branch of the Atomic Energy Commission and as Assistant Deputy Chief of Staff for Development for Nuclear Systems of the Air Force.

You are, of course, aware of the many complex technological problems involved; however, within the scope and level of the reoriented program, we believe this organizational realinement, with its centralized authority, will permit the most effective direction possible.

Sincerely yours,

——— ———, *Chairman.*

OFFICE OF THE SECRETARY OF DEFENSE,
Washington, D.C., November 20, 1957.

Hon. CARL T. DURHAM,
Chairman, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. CHAIRMAN: Attached herewith is an exchange of correspondence between the Air Force and the Atomic Energy Commission which concerns the establishment of an integrated office for managing the aircraft nuclear propulsion program.

Sincerely yours,

HERBERT B. LOPER,
Assistant to the Secretary of Defense (Atomic Energy).

OCTOBER 31, 1957.

Mr. K. E. FIELDS,
General Manager, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR MR. FIELDS: As previously discussed with the Commission, the Air Force has been studying various organizational concepts whereby the appropriate Air Force elements could be merged with the AEC Aircraft Reactors Branch to form an integrated office for managing the joint ANP program. We now feel that we have arrived at the most practical approach to integrating the management activities of the two agencies in keeping with current status and objectives of the ANP program for the next several years.

In order to effect an integrated management organization at the earliest possible date, we would propose an integrated project office be established between the Air Force and the Atomic Energy Commission by complementing the present Aircraft Reactors Branch with suitable Air Force functions, together with approximately 18 additional Air Force spaces. If the Commission feels that it can provide suitable additional office space and administrative support to accommodate the increased size and scope of operation of this office, it is proposed that the office be located with the Division of Reactor Development in the headquarters of the Atomic Energy Commission. The integrated office would be responsible for the complete propulsion system development, and with the concurrence of the AEC, would be headed by Maj. Gen. D. J. Keirn, who would be delegated Air Force authority commensurate with the AEC authority he has held as Chief, Aircraft Reactors Branch. In addition, General Keirn would retain his Air Staff position as Assistant Deputy Chief of Staff, Development for Nuclear Systems, Headquarters, USAF.

As you know, the ANP program has been redefined to encompass the development and developmental testing of nuclear powerplants for aircraft, the development of radiation shielding and components of aircraft systems, and the provision and use of suitable flight test vehicles for testing nuclear powerplants in flight. The ANP program also encompasses similar activities pertaining to nuclear propulsion for missiles, nuclear auxiliary powerplants for use in aircraft or missiles and such other nuclear devices that may be subsequently assigned to the program. Accordingly, the integrated office will be directly charged with the responsibility for the development of nuclear propulsion systems. As such, technical direction functions of the Air Force GE–ANPD contract will be transferred from the Air Research and Development Command to the integrated office. However, ARDC will continue to be responsible for other portions of the ANP program which are not specifically a part of the propulsion system, such as the development of vehicles for flight testing the propul-

sion system, flight vehicle shielding, and subsystems other than the propulsion subsystem. On the ARDC effort, the integrated office will be the executive manager to insure the appropriate planning and execution of development for each element of the ANP program as defined herein.

If this general arrangement meets with the approval of the Commission, it is proposed that it be implemented immediately and that General Keirn be jointly instructed to take the necessary action to establish the integrated organization and devise and implement the necessary administrative procedures within both agencies to effectively accomplish the joint ANP program within the framework described above.

Sincerely,

CURTIS E. LEMAY,
General, U.S. Air Force,
Vice Chief of Staff.

NOVEMBER 7, 1957.

Gen. CURTIS LEMAY,
U.S. Air Force, Vice Chief of Staff, Department of the Air Force.

DEAR GENERAL LEMAY: Your letter dated October 31, 1957, proposing an integrated project office for managing a joint ANP program has been given careful study. We believe it contains all of the basic elements needed for successful single management of a joint AEC–USAF program of this magnitude and, in fact, closely parallels our previously stated views of what such an organization might logically be.

The Commission is fully in accord with the selection of Major General Keirn to head the integrated organization. General Keirn will be instructed to implement immediately, in coordination with your headquarters, the actions required to establish the joint organization. In this connection the Commission can provide the necessary facilities and administrative support to accommodate the proposed integrated project office.

Sincerely yours,

R. W. COOK,
Acting General Manager.

APPENDIX C

SPEECHES AND TECHNICAL ARTICLES

1959

NUCLEAR POWERPLANT DEVELOPMENT FOR AIRCRAFT PROPULSION

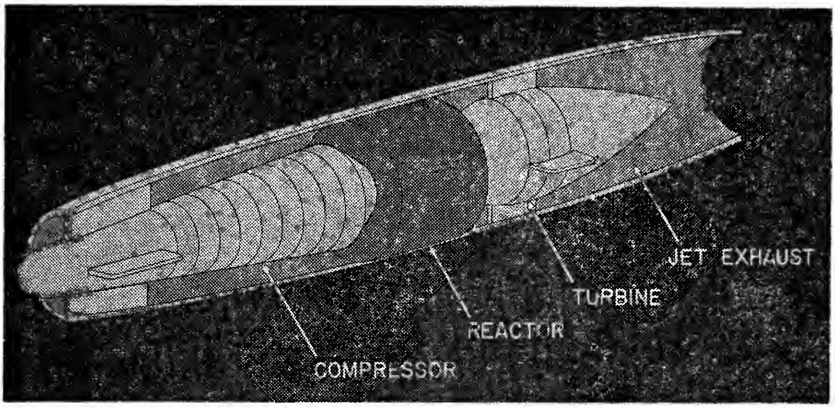
(Address by D. R. Shoults, general manager, Aircraft Nuclear Propulsion Department, General Electric Co., at a joint meeting of the Engineering Society of Cincinnati and the American Society of Mechanical Engineers, Cincinnati section, Cincinnati, Ohio, on January 15, 1959)

As most of you already know, the Aircraft Nuclear Propulsion Department of the General Electric Co. is engaged in research and development work to produce a nuclear powerplant for aircraft. We are working under contracts with the U.S. Atomic Energy Commission and the U.S. Air Force. This effort is the primary work of this type being done in the United States.

Nuclear power for any application is extremely attractive because of the large amounts of energy contained in small amounts of fuel. Probably you have heard that the complete fission of 1 pound of uranium 235 liberates heat equal to that liberated by the burning of 1,700,000 pounds of gasoline. In nuclear-powered flight, aircraft will be able to fly for long periods on small amounts of fuel; fuel will be measured in pounds per week rather than in thousands of pounds per hour.

Our goal is to provide a turbojet engine in which heat is provided by a nuclear reactor rather than the conventional chemical-fuel combustion chamber (fig. 1). In a nuclear-powered turbojet engine, air is drawn in through the intake into a compressor. The compressed air is heated in a reactor and then flows through the turbine and out of the exhaust nozzle. The jet of hot gases leaving the nozzle provides thrust for the aircraft. A shaft operated from

POTENTIAL NUCLEAR POWER PLANT



the revolving turbine blades provides the mechanical energy that operates the compressor.

The engineering challenges here include containing the radioactives materials within the reactor, providing shielding around the reactor to localize the radiation, providing sensitive, reliable controls for the powerplant, and developing long-life components of high-performance materials that can withstand the environment of high temperatures and nuclear radiation.

In talking with you tonight, I want to review for you some of the progress that we have made and to describe the performance and applications of the airplane that our engines will power in the future.

But first, let me recall some of the history of the aircraft nuclear propulsion program. It started in 1946 when the Fairchild Engine & Airplane Corp. began a feasibility study at Oak Ridge, Tenn. Their study was successfully concluded in 1951 and the General Electric Co. was asked to develop a turbojet propulsion system. This system, which I described for you a moment ago, is the simplest and most straightforward of the possible ANP powerplants.

Many of the personnel working for Fairchild who elected to remain in this type of work were engaged by General Electric when this transition took place. The project was assigned to the General Electric Aircraft Gas Turbine Division, which had just moved to Cincinnati from Lynn, Mass. In 1953, department status was gained and the department was placed in the Atomic Products Division.

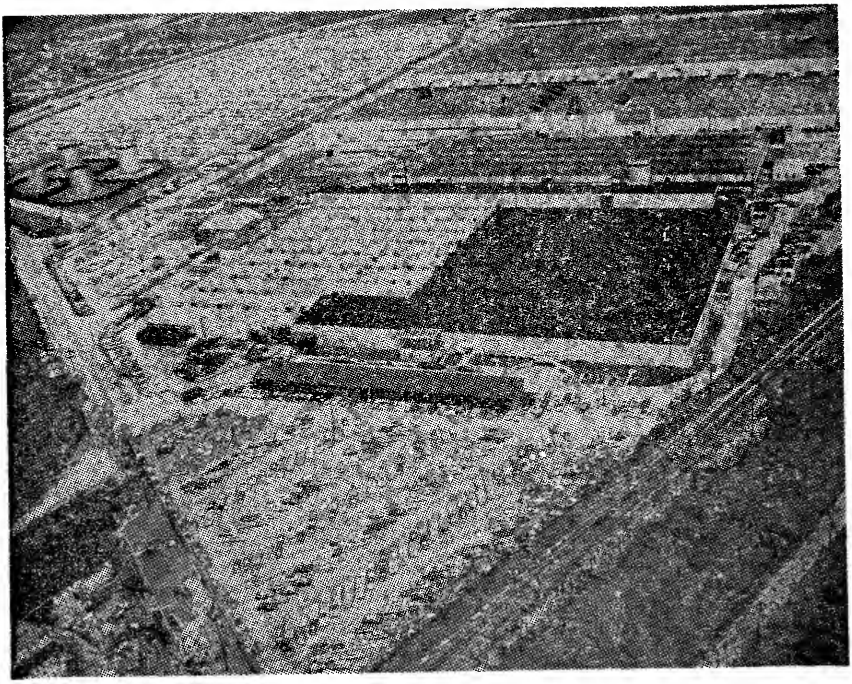
The department currently occupies several buildings in the Evendale area (fig. 2) and also operates an Idaho test station, which is a part of the National Reactor Testing Station near Idaho Falls, Idaho.

A nuclear powerplant was planned for an existing Air Force plane with limited military potential, a modified B–36. This program was abandoned in 1953. A subsequent evaluation of the reoriented ANP program resulted in further changes in 1956.

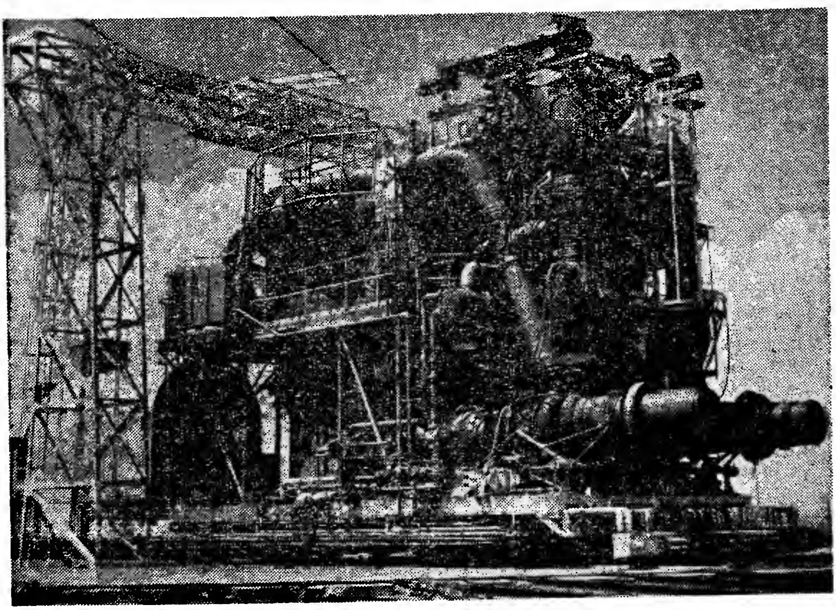
The work done prior to the program changes cannot be considered as effort not pertinent to our engineering progress. Most of the basic research and design, development, and testing of early assemblies has generated information and technological know-how that would be required regardless of the flight-version powerplant.

With our present level of technology, it is possible for us to build a nuclear powerplant capable of providing sufficient thrust to fly an airplane. This fact indicates that we have made substantial headway in solving the almost overwhelming problems that faced us in 1951.

Some of our progress was revealed recently in press releases stating that we operated a modified turbojet engine on nuclear power for extended periods of time in tests that ended early in 1957. The test was called heat transfer reactor experiment No. 1.



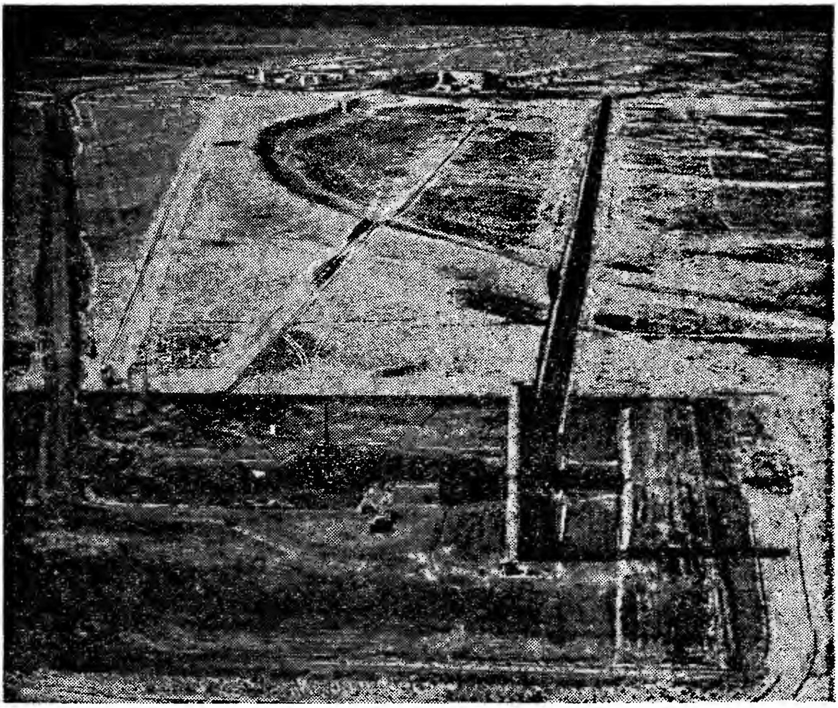
The development assembly provided for the test was mounted on railroad trucks (fig. 3). It consisted of a reactor, a radiation shield, two turbojet engines, duct-



ing, control components, and the necessary instrumentation that our engineers needed to gain detailed information about all aspects of the tests. This assembly of equipment is aptly called the core test facility, since it was designed for the insertion of different reactor cores as they are developed.

The core test facility is a veritable laboratory on wheels. No attempt was made to restrict the size and weight to approximate a flight version; rather, the assembly was deliberately made large for ease of access and for the extra equipment used to gather information in complete detail. An extra engine was even provided to guard against delay if engine trouble were encountered.

Figure 4 shows the Idaho test site. On the left in the background are the



office and engineering facilities. On the right is the shop area and, in the foreground, the nuclear test facilities. The core test facility was assembled in the shop area and transported to the test area by a specially constructed, heavily shielded locomotive. As you can see in figure 3, railroad tracks connect the shop and the test facility.

Pictured in figure 5 is a drawing of the initial engine test facility, which is designed to accommodate nuclear operation. Shown here is the test platform, the coupling station with utility and instrumentation connections, the data processing room, and the equipment room. The exhaust stacks carry off the effluent from the engine operation.

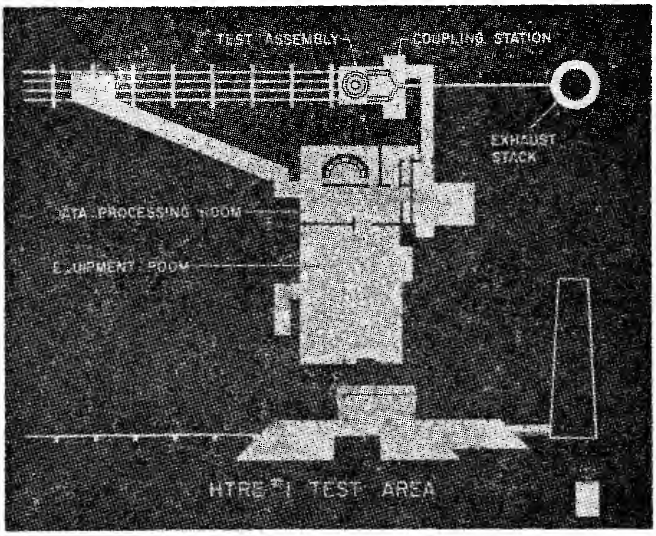
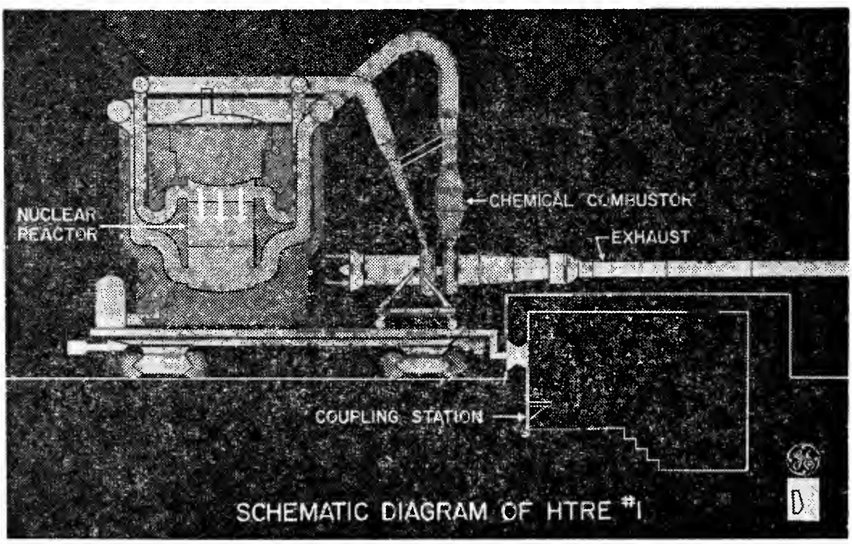
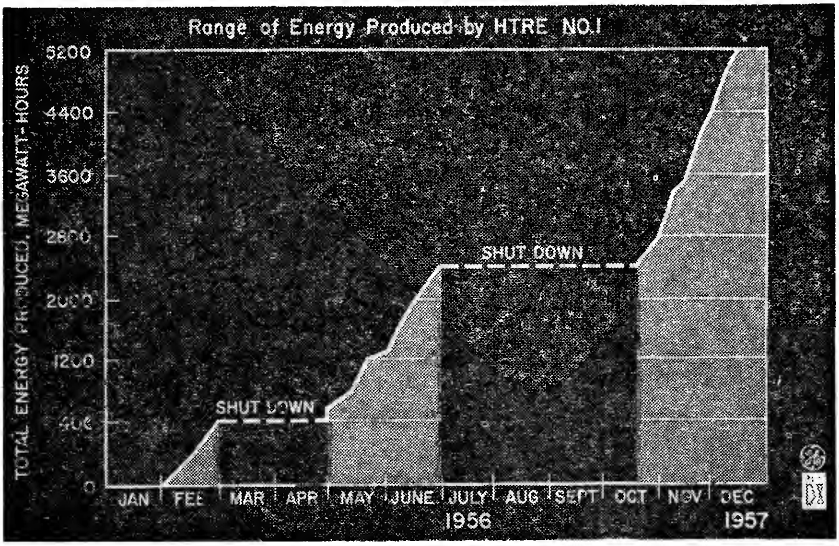


Figure 6 is a drawing of the assembly connected for test. Operation of the equipment is as follows: Air is drawn into the engine at the intake shown near the center of the drawing. Air is compressed and then sent through the reactor to be heated. Additional heat, when required, is added to the flow by the chemical combustor. The heated air then passes through revolving turbine blades and out the exhaust-handling duct.



The developmental assembly was first operated on chemical power only. No attempt at nuclear operation was made until a checkout of the entire system was completed. Then, early in 1956, the transition from chemical to all-nuclear operation was realized. The engine was always started on chemical power. As the reactor heat increased, chemical heat was decreased to maintain a constant temperature at the turbine inlet. Finally, when the air from the reactor was hot enough to operate the system, the chemical heat was no longer needed.

After the first transfer to all-nuclear power was made, operation continued for 6 hours. In subsecquent testing, which took place over the course of a year, 150 hours of all-nuclear operation was accumulated. The total energy output from chemical and nuclear sources was over 5,000 megawatt-hours (fig. 7).



If all this energy had been converted to electricity, it could have lighted the homes in a city the size of Pasadena, Calif., for an entire month.

This series of tests was invaluable to us. It verified the feasibility of our design, and it demonstrated the predicted performance of the powerplant, the lifetimes of key components, and the operation of control components. Also successfully demonstrated was the remote-handling equipment developed for servicing and disassembling of this and subsequent test assemblies. The data obtained provided us with firsthand information and experience for future design, research, and development activities.

The reactor developed for the test was air cooled and water moderated and had metallic fuel elements. The shield surrounding the reactor was made of water, lead, and steel. More specific information about the assembly is, of course, security classified.

Progress made since the HTRE-1 testing has not been made public for security reasons. I can assure you, however, that additional successful work has been accomplished and that the HTRE-1 testing contributed significant information to our activities since that time.

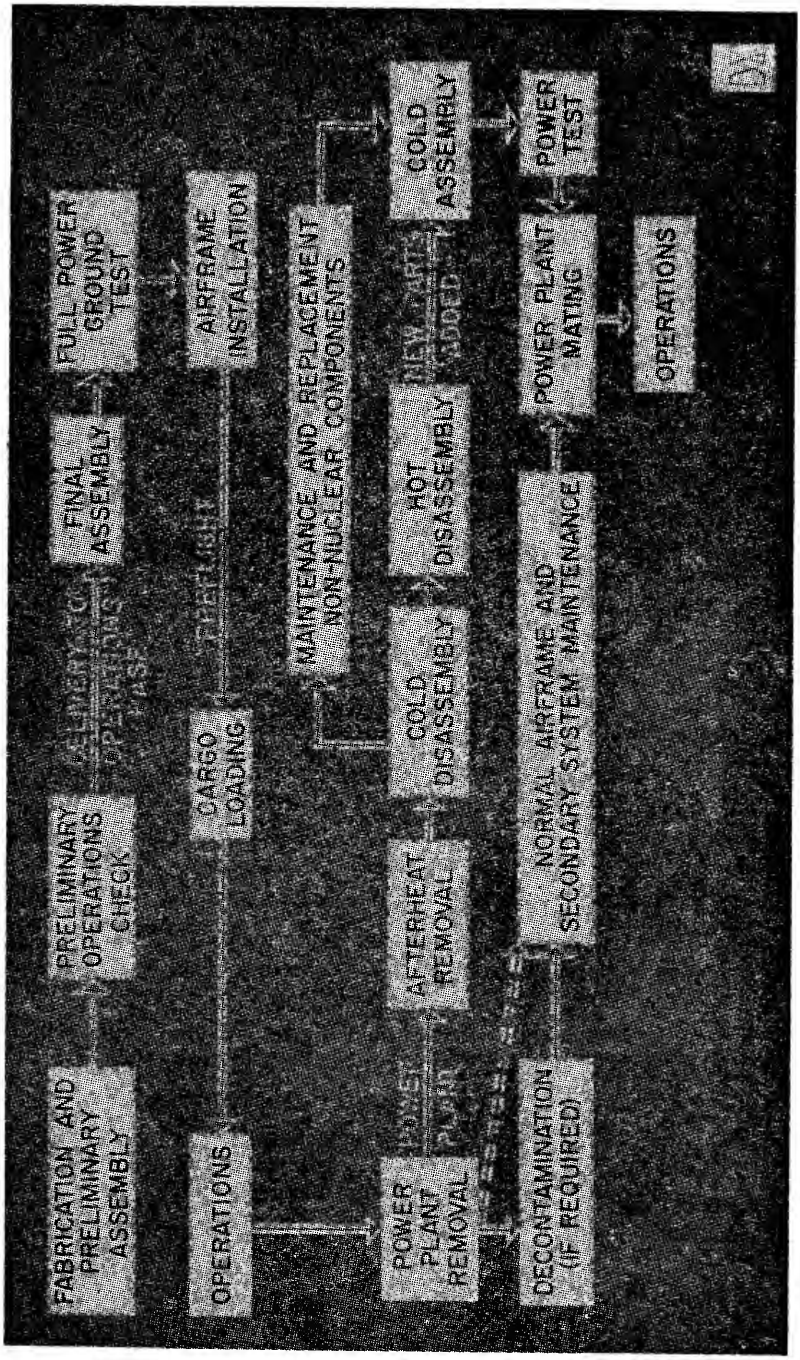
Let us turn now to the airplane of the future with its nuclear powerplant. The most important and unique feature of such an airplane is its long range and endurance. Just as the nuclear-powered submarines have been able to spend days and even months on a single mission, a nuclear-powered aircraft will have a similar endurance potential.

The length of mission will bring about a new environment for aircraft crews. They will essentially "live" on the airplane rather than taking it from place to place. Two crews for a mission is a very real possibility. Such protracted missions will also require suitable crew quarters.

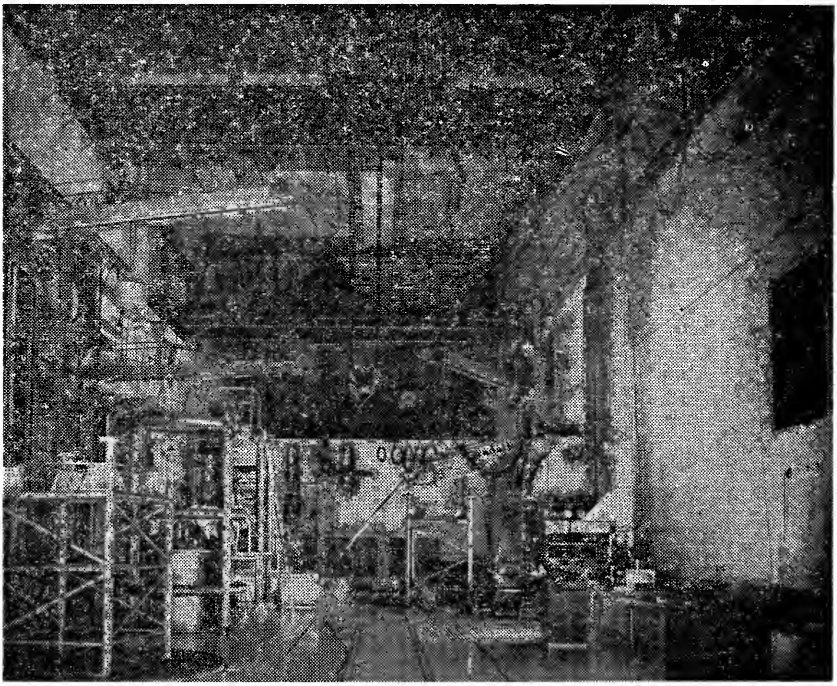
Probably the greatest difference between aircraft with nuclear and chemical powerplants is in the ground-handling procedures.

Since the reactor is radioactive, it will receive special handling after the plane has landed and the reactor is no longer operating. It is necessary for designers to give this matter their utmost attention in designing the powerplant. Ease of maintainability must be designed into the powerplant and at the same time special equipment and fixtures can be devised to handle the powerplant during its maintenance cycle.

Figure 8 shows the procedure of maintenance. After landings, the airplane and powerplant are demated. Each goes its separate way. The airframe undergoes servicing that is not radically different from that of conventional aircraft. The powerplant, on the other hand, must be treated differently because of the radioactivity present. To get the plane airborne again in a shorter time, spare powerplants that are not radioactive can be provided.


FABRICATION AND PRELIMINARY ASSEMBLY
PRELIMINARY OPERATIONS CHECK
FINAL ASSEMBLY
FULL POWER GROUND TEST
AIRFRAME INSTALLATION
CARGO LOADING
OPERATIONS
MAINTENANCE AND REPLACEMENT NON-NUCLEAR COMPONENTS
COLD ASSEMBLY
POWER TEST
POWER PLANT REMOVAL
AFTERHEAT REMOVAL
COLD DISASSEMBLY
HOT DISASSEMBLY
NEW PARTS ADDED
POWER PLANT MATING
OPERATIONS
DECONTAMINATION (IF REQUIRED)
NORMAL AIRFRAME AND SECONDARY SYSTEM MAINTENANCE

To give you some idea of what the "hot" maintenance facilities would be like, our hot shop facility in Idaho is shown in figure 9. The room is encased with 7-foot-thick concrete walls and has 6-foot-thick viewing windows.



Manipulators are operated from control points on the outside of the shop. Manipulator operators view their work through the viewing windows with the aid of binoculars. The HTRE–1 developmental assembly was built, torn down, and reassembled in this shop. Much of the work had to be done by remote means.

Shielded vehicles will be needed to transport hot power packages from the airframe to the shop. Another kind of vehicle that will be required is for removal of reactor heat after reactor shutdown. During operation, a reactor produces large amounts of fission products that are unstable. By unstable, I mean that they continue to emit radioactivity. This decay process results in the release of a small amount of heat similar to that from the primary fission process.

Besides the auxiliary aftercooling mobile equipment, the reactor afterheat could be removed by operating the powerplant on chemical power to keep airflow moving through the system.

Another difference between nuclear and conventional airplanes stems from the difference in fuel. Although huge amounts of liquid fuel are eliminated, a nuclear powerplant requires a radiation shield adequate to protect the crew, cargo, and aircraft structure from the radiation generated in and emanating from the reactor. The size and weight of shielding is equal to a portion of the liquid-fuel weight and volume.

Aircraft design will be affected to some degree by the shielding requirements, because the crew, of course, must be given primary consideration in the distribution of shielding.

The possible military applications of aircraft powered by nuclear means include:

1. Bombers.
2. Reconnaissance aircraft.
3. Cargo or troop carriers.
4. Tankers.
5. Anti-submarine-warfare aircraft.
6. Air early warning and control aircraft.
7. Air missile launchers.

The interest in nuclear propulsion on the part of the U.S. Air Force was revealed in a recent speech by Maj. Gen. D. J. Keirn, Deputy Chief of Staff in Charge of Development for Nuclear Systems, where he described our present defense status as follows: "In the face of the threat of a possible surprise attack, our deterrent posture can be maintained only by positively insuring the survival of an effective retaliatory force. At present, the Strategic Air Command bomber force is operating under a ground-alert concept which will enable us to react within 15 minutes of the initial warning with a significant portion of the fleet."

He went on to say: "In the future our planning will include the addition of hardened ballistic missile launching bases, and employment of a portion of our manned Strategic Air Command fleet on airborne alert, if necessary."

"An ideal airborne-alert manned aircraft system must carry a large payload and remain on nomadic patrol for extended periods of time in various areas of the world. It must maintain continuous communication with appropriate headquarters and be capable of instantaneous reaction with air-launched missiles. When required, the system should be capable of following up the missile launching phase with a low-level, high-speed penetration of the enemy's heartland, in order to seek out and destroy hardened targets or targets whose locations are not sufficiently well known to permit attack by long-range missiles. The combination of these features can best be achieved through the application of nuclear propulsion."

When we think in terms of commercial use of nuclear-powered aircraft, the picture changes somewhat.

It would appear that nuclear-propelled commercial aircraft will follow economic applications of both land and marine nuclear powerplants. In fact, it is likely that the introduction of economic commercial-aircraft nuclear powerplants will follow the pattern of chemical turbojets. It took about 15 years from the time the military first operated jet aircraft until commercial use of jet aircraft became widespread. Therefore, it appears that the early use of ANP powerplants will be in military applications where the higher individual cost can be justified because of the greatly improved military capabilities of the airplane. It should be noted that there are several potential military missions with unique requirements, as compared to commercial needs, that permit optimum exploitation of the inherent endurance characteristics. In some of these military missions, when it is desirable to remain continuously airborne for some days, it appears that nuclear-propelled aircraft will actually have lower operating costs than chemical turbojet aircraft. Nuclear-powered aircraft will not require expensive, time-consuming inflight refueling. Although there might be a requirement for a few very long-range commercial airplanes with a nonstop range of as much as 10,000 nautical miles, this still, would require a flying time of under a day. Therefore, special military missions will be able to justify nuclear airplanes on an economic basis some years earlier than commercial nuclear airplanes.

Developing a safe, reliable nuclear powerplant for aircraft must be accomplished within exacting specifications and despite the limitations imposed by size, weight, and shielding requirements. These complicating factors make our effort an engineering task that is major in scope but by no means insurmountable. Our enthusiasm is constantly regenerated as we look to the future—a future in which nuclear power plays an increasingly important part.

Placed in the limelight by constant publicity, we must be positive that our work is based on sound technology. For this reason, each phase of our development program is carefully conceived and meticulously executed. Our progress thus far has been rewarding.

DEPARTMENT OF DEFENSE

OFFICE OF PUBLIC INFORMATION

Washington, D.C.

News Release, No. 82–59

ADDRESS BY MAJ. GEN. DONALD J. KEIRN, USAF, ASSISTANT DEPUTY CHIEF OF STAFF, DEVELOPMENT, FOR NUCLEAR SYSTEMS, HEADQUARTERS, USAF

Before Symposium on Aerospace Technology, Institute of the Aeronautical Sciences, Astor Hotel, New York, N.Y., Wednesday, January 28, 1959

It is indeed an honor and a privilege to speak to the leaders of American aeronautical science on this occasion. As I look back over the years I have been in the propulsion development business, it is difficult to believe that so much has taken place in what seems like so few years.

These years have witnessed a tremendous increase in the might of American aerospace power. As the pace of technological progress keeps quickening, it is difficult to imagine what effect a similar number of years will have on our future defense posture. Whatever the effect may ultimately be, I feel certain that nuclear power will play an ever-increasingly important role.

As a military man I will restrict my remarks to nuclear programs which are primarily oriented to defense applications. However, it is comforting to realize that our defense effort exerts a very positive stimulus on the country's total technical state of the art. Certainly the contribution to our civilian economy and technology is considered. But this is another story. For now, I hope you will find the defense side of the discussion interesting and informative.

The aeronautical and astronautical nuclear power program can be subdivided in four major areas. These are turbojet propulsion for manned aircaft, ramjet propulsion for atmospheric missiles, rocket propulsion, and auxiliary power supplies for space vehicles. I will discuss each in turn.

I think that it is appropriate to begin with the manned aircraft program since its origin dates back further than the others. We started on this project shortly after the close of World War II at which time we were not at all sure that an aircraft powered by nuclear energy was possible. I will not take you over the long and tortuous road we have traveled since then, but today I can say with confidence that manned nuclear-powered aircraft are possible and, I believed inevitable.

The question of flying one depends upon a continuing effort to slove engineering problems and a great deal of powerplant testing. This, in turn, hinges on financial support and suitable priorities. Inherent in these factors, of course, are the decisions regarding objectives. Is a simple demonstration desired or a useful aircraft? It has been decided, and rightfully so, that this country's nuclear powered airplane program should be aimed toward producing a militarily useful aircraft.

But how is a militarily useful nuclear-powered aircraft defined? During my long experience in the Air Force, we have always been hampered by the limited amount of energy in a fuel tank. We have continually striven to increase range and the amount of time we can spend in our element, air. This implies such ideas as true global capability, or any other similar expression you may wish to use. Nuclear power adds a vital dimension to aircraft, endurance, and extended range, and dictates a new analysis of our concepts of aircraft in the national defense.

In the strategic area this could mean a mobile missile launcher on nomadic patrol, invulnerable to surprise attack, thereby assuring any nation contemplating aggression a devastating retaliation. It could mean a penetrating bomber with omnidirectional approach capability over a wide spectrum of altitudes and speeds. It could mean a system which provides us with a continuous airborne early warning and surveillance capability. It might mean global support for limited war operations. By merely being there, the nuclear system would exert a powerful deterrent influence. In the mission areas of air defense and logistics, similar thinking is evolving into new operational concepts.

Recent progress in aircraft design and integrated shielding techniques brought overall system design weights and amount of potential radiation damage to airframes down to the point where we can begin to take advantage of nuclear

power, and remain in the air for extended periods of time. For instance, crew dose rates are down to where each crew may fly 1,000 hours per year on nuclear power for many years including missions of well over 100 hours duration each.

This progress is the direct result of years of comprehensive development and radiation testing on materials, components, and assemblies. Flight experience with the modified B–36 nuclear test airplane contributed a great deal in the shielding and ground handling areas. We conducted 47 flights with a 1 megawatt reactor and a shielded crew compartment installed. By judicious choice of materials and adroit engineering, we can proceed into a flighth test program with confidence that the parts of the airframe subjected to radiation will function as required during the period of flight test. Special procedures and equipment will have to be employed, but there is no reason that theses cannot be reduced to practice. However, positive solutions to all the problems must await the practical experience of operating a nuclear-powered airplane. This is, indeed, one of the primet objectives of the flight-test phase.

We have examined in as much detail as present knowledge permits the potential hazards associated with operation of nuclear-powered aircraft. By using our accident experience with all our experimental jet aircraft, we have analyzed the additional risks that would have been imposed had these aircraft been nuclear powered. Through such analyses, we have devised tentative operational procedures, and have determined the requirements which should be imposed upon flight test and operational bases.

In conducting these analyses, we have employed what we believe to be pessimistic assumptions with regard to all critical parameters affecting nuclear hazards in event of accident. We have concluded that proper selection of bases and appropriate flight controls will reduce the hazard to the public to levels not materially exceeding those associated with the operation of other military aircraft.

Work on the propulsion system is currently being directed along two separate paths, the direct and indirect cycle systems. Each has its advantage and disadvantages. Many significant technical achievements have been accomplished, each of which has tended to increase confidence in our ultimate success. Both programs are immeasurably contributing to advanced reactor technology which, of course, will eventually pay off in more efficient exploitation of fission energy for such things as power generation for industrial and home consumption.

To date, the Air Force and the Atomic Energy Commission have spent over three-quarters of a billion dollars on the manned-aircraft program. For this dollar expenditure, we feel that we have sufficiently investigated all of our critical problem areas to the extent that we are ready to proceed with a program leading toward developmental flight testing as the next logical step. I am confident that flying a practical aircraft which can be adapted to military operations is a matter of time only.

The next program of interest is the nuclear ramjet development, known as Project Pluto. Under Atomic Energy Commission contract, the E. O. Lawrence Laboratory, formerly the University of California Radiation Laboratory, has prime development responsibility. This project is relatively new. The present objective is the feasibility demonstration of the reactor under environmental conditions of temperature and power density suitable for ramjet propulsion. The Air Force has a supporting role during this phase in the form of providing certain testing hardware and services and conducting application studies.

A missile employing the nuclear ramjet possesses several very interesting capabilities which make it particularly attractive. It has the highest payload to gross weight ratio of any intercontinental strategic system. This is the principal reason it has a relatively favorable cost effectiveness factor when compared to other systems. It can penetrate at supersonic speeds for extreme ranges at low level if desired. Since it is aerodynamicaly controlled, it can change direction and dogleg. By taking advantage of monitored inertial guidance techniques during all portions of the mission, excellent weapon delivery accuracies should result. In addition, when it is realized that defense techniques and equipment employed against low altitude penetration are radically different from those employed against high altitude penetration, the magnitude and severity of the defense problem imposed on the enemy becomes readily apparent.

Attractive as this application appears to be at present, we must wait for much more test data and analyses in all phases of system and subsystem opera-

tion before we will be in a position to realistically evaluate its rightful role.

In an even higher temperature regime than either the turbojet or ramjet is the nuclear rocket. The development program in nuclear rocketry, called Project Rover, is a long-range effort with tremendous growth potential which will eventually provide significant capability for space travel. The current development approach on the heat exchanger type reactor is an auspicious start, and one which is amenable to known techniques and engineering methods. The Los Alamos Scientific Laboratory, under Atomic Energy Commission contract, has prime responsibility for this effort. Several technical approaches on the reactor are being pursued. The reactor ground test program should establish the preferred course for initial flight prototype development. The supporting role in this effort in the form of testing hardware and services has been recently transferred from the Air Force to the National Aeronautics and Space Administration. The Air Force is continuing to evaluate possible military applications.

The heat exchanger type system currently under development can provide specific impulses from two to three times that obtainable from the most advanced chemical counterpart. This is a direct result of using low molecular weight propellants such as hydrogen. With increasing payload, there is a crossover point at which this system becomes competitive with, and then finally surpasses, chemical systems. I predict that it will be successfully developed and will see extensive service in the national space program. Such a rocket engine can be advantageously employed either as a primary booster or as a stage in conjunction with the more conventional types of rocket engines we now employ. Also under study is a variety of more sophisticated methods of better utilization of the energy available from the fission process. We fully expect that this effort, or the present developmental effort, or both, will uncover new techniques and approaches which will evolve into higher performing systems. Therefore, it is my opinion, that in the distant future, we will rely almost entirely on nuclear propulsion for space travel.

The fourth line of endeavor I would like to discuss is the development of nuclear auxiliary power devices as a source of electrical power for satellite or space vehicles. This program is called SNAP which stands for systems for nuclear auxiliary power. All space missions will require electrical power for communications, control and guidance equipment, computers, and instruments. Power requirements for future applications are tending to increase as the planned experiments and projects become more ambitious. For example, current satellites use several watts of power, but it may require kilowatts of power to televise live from a lunar orbit or to communicate between Mars or Venus and the Earth.

Chemical systems such as batteries are limited in total energy capacity. Current satellites are employing this total capacity at low wattage levels in order to prolong life. Since satellites or other space vehicles are essentially long-lived devices, we would like to utilize their potential on orbit to the maximum extent practicable. Conventional energy surces do not allow us to do this, but excellent progress is being made toward harnessing other available sources. Devices employing solar energy, for instance, are under development. These have certain inherent advantages and disadvantages and, certainly, development effort will continue. The Atomic Energy Commission has quite properly focused its attention on both radioisotope, and nuclear reactor energy sources. Both direct conversion, which depends upon the thermoelectric effect of materials, and conventional thermodynamic cycle conversion are being utilized to transform nuclear energy into useful electrical energy. Significant progress is being made on both the energy sources and the conversion techniques. Indeed, a small radioisotope powered direct conversion device has been recently successfully demonstrated. This unit, fueled with polonium 210, weighs approximately 5 pounds and produces 5 watts of useful electrical energy at efficiencies of about 8 percent.

For truly bold ventures into space, the high-powered nuclear reactor turbo-electric system in the megawatt range may be the only solution. Here again, the Atomic Energy Commission is currently supporting basic work which may lead to development of a prototype system. The higher power range may also have application to vehicles employing electrical propulsion schemes such as the ion accelerator. Whereas the rocket engine, either nuclear or chemical, produces high thrust for a short duration, the ion rocket provides low thrust

with resultant low acceleration for very long periods of time. Its utility, therefore, will probably be restricted to interorbital transfer, such as from an Earth orbit to an orbit around Mars or Venus.

A key problem associated with all power generating cycles on space vehicles is the requirement for the rejection, by radiation, of large amounts of heat waste. The size of the radiator required for heat rejection can be reduced by increasing cycle operating temperatures. This, of course, imposes stringent materials and operating requirements on all portions of the energy conversion circuit. Thus, the requirement is established for continuing advanced research and development. In evaluating space systems, it is well to remember that not only is it necessary to optimize the heat source, radiator, and conversion equipment as separate components, but it is also necessary to optimize the system as an integrated entity in order to achieve optimum specific power. From this brief discussion it should be quite apparent that we have just scratched the surface in this area.

Now that I have worked myself into the astronautics and space regime, I would like to close with a few personal observations concerning this interesting realm not specifically related to nuclear power. I have heard many reasons for space stations, and I offer a reason of my own which I have not previously heard advanced. I'm certain each of us has wondered about the possible existence of intelligent beings elsewhere in the universe. To date we have no proof, but the excitement caused by reports of unidentified flying objects merely emphasizes our innate curiosity. It is my firm belief, however, that if intelligent beings do exist somewhere else, we may eventually identify their existence through the interception of their communications before we meet them face to face. If they do exist, it is entirely possible that some of them may have passed through our stage of evolution, and may have already achieved a higher level of social and technological culture than our own. The fact that they have not already explored us, or discovered us as it were, could attest to the difficulty of the undertaking. Nevertheless, one might also assume that they use natural phenomena such as electromagnetic energy for communications. It may be possible to pick up these communication signals if they do exist. They may be so attenuated by the time they reach the earth as to be inaudible within the background noise level existing on our planet. Because of the lack of an atmosphere, I would expect the background noise level on the moon, or on a space station, to be relatively much lower. This should result in much better reception of low order energy signals.

In listening for signals, I would attempt to distinguish orderliness from randomness. If contact were established with some unknown origin, it is not inconceivable that informative conversation could take place, ultimately evolving into visual communication. Because of the wealth of information and knowledge which might be gained through this means, I consider this another good reason for establishing a moon station or other suitable space station. Obviously, such a station would have other uses, some maybe even less credible than the one I mentioned, but I doubt if success in any other project conducted from a space station would provide a more dramatic impact than that created by a positive announcement that intelligent beings do exist elsewhere in the universe.

In concluding my remarks, let me return to my subject. I am convinced that nuclear power for aeronautical and astronautical applications is here to stay. We are on the threshold of an entirely new and exciting era. It is going to take the combined efforts of us all, working as a Government-industry team, in order to realize the full potential available. As far as I can ascertain, our embryonic programs are pointed in the right direction. Through perseverance, I have every confidence that we can hold them on course and achieve our goals.

ENGINEERING NEWS-REPORT BROADCAST BY MAJ. GEN. D. J. KEIRN, ASSISTANT DEPUTY CHIEF OF STAFF, DEVELOPMENT FOR NUCLEAR SYSTEMS, HEADQUARTERS U.S. AIR FORCE, FEBRUARY 6, 1959

I feel greatly honored that Engineering News-Report should proffer me their "easy chair" from which to chat on any subject next to my heart. As an Air Force officer in charge of the program to develop nuclear power for the propulsion of aircraft and missiles, and auxiliary nuclear power devices for space application, I find it difficult to be selective in my choice of a subject. There

is one matter, however, which I believe has broader implications than any specific application of nuclear power, one of particular concern to the American public. This has to do with the dangers of nuclear radiation. Now I am not a radiobiologist so I am not going to talk about the biological effects of radiation on the human body, but rather about the problems of making progress in the development of nuclear power for either military or civilian purposes in the face of potential radiation hazards.

The effects to the civilian population of radioactive fallout from weapon tests and of radioactive contamination from accidental releases of radioactive material due to malfunctioning of reactors or other nuclear devices has received much public comment in the news media. It is natural that we should be greatly concerned over these hazards about which we are still learning. The problem obviously arises in connection with the utilization of reactors in aircraft which must be airborne and have some degree of freedom of movement in order to be useful. The possible hazards associated with the crash of such an airplane has led to doubt in many people's minds as to the overall usefulness of nuclear-powered aircraft, and these doubts could, in fact, retard the development of nuclear fuel for the air and space age.

Now I would not wish to belittle or criticize those who express such a high concern over these dangers of air and ground pollution with radioactive materials. I can assure you that the Air Force and Atomic Energy Commission are extremely sensitive to their responsibility for insuring the safety of the public in all of our test and tactical operations. We must not permit ourselves to create a problem of widespread contamination that could have deleterious effects on the lives of our children and their children. We also must not put ourselves in a position which would impede technological progress.

Let us take as a simple analogy the pollution of our streams, rivers, and lakes. Many of us who like to hunt, fish, and swim regret that more vigorous efforts were not taken by our forefathers to prevent such contamination, and indeed many expensive projects are now underway to undo our lack of earlier foresight. But how could our forefathers have prevented such contamination? Should they have banned the use of rivers for transportation? Should they have banned the construction of factories and mills along our waterways? I cannot believe our country would be as great as it is had we done so. But could we not have insisted on proper sewage-disposal plants? Could we not have insisted on proper handling of waste from factories? Could we not have insisted on proper application of sanitation principles in river navigation? All of these things we might have done. So my thesis is simple—in the broad sense, let us not protect ourselves from air and ground pollution caused by the release of radioactive materials by banning the use of nuclear devices or the development and testing of what otherwise would be useful devices; but rather let us assure ourselves that we have taken the necessary steps in the employment of these devices which will insure the maximum degree of public safety compatible with technological progress for the future benefit of mankind.

NUCLEAR AIRCRAFT PRESENTATION TO WASHINGTON CHAPTER OF INSTITUTE OF AERONAUTICAL SCIENCES BY COL. WILLIAM A. TESCH, USAF (APRIL 14, 1959)

I appreciate this opportunity to discuss the aircraft nuclear propulsion program. As you know, the Air Force has been engaged in this program for many years now, since early 1946, and, together with the Atomic Energy Commission, has expended considerable effort toward the objective of achieving useful nuclear propulsion systems. Before going into the technical problems associated with these systems, I would like to discuss briefly the role of manned nuclear aircraft as we presently foresee it.

In aircraft applications nuclear propulsion inherently provides essentially unlimited range and endurance, large payloads, and attractive low-altitude performance. In the strategic mission area these characteristics can be translated into a global range capability independent of tanker refueling and overseas bases, with the added flexibility of omnidirectional penetration into regions of relatively weak enemy defenses. In addition, in the past few years the extended endurance features of nuclear aircraft have taken on added significance in terms of providing an airborne alert potential to our deterrent posture. An even more recent adjunct to the nuclear system is the advent of air-launched ballistic missiles which could be brought to bear on high priority targets almost immediately from

the aircraft on airborne alert. The combination of these characteristics would provide a mobile missile launcher to operate on nomadic patrol and to be relatively invulnerable to surprise attack. In the same aircraft on the same mission, this combination provides a low-altitude penetrating bomber with the capability of omnidirectional approach for hard-target destruction, armed reconnaissance, and ICBM/IRBM weapon miss followup. This kind of system has been referred to as the CAMAL system, derived from continuous airborne alert, missile launch, and low-level penetration.

In the mission areas of aircraft early warning, antisubmarine warfare, patrol and logistics, the combination of range, endurance, and payload is equally as attractive in these as the CAMAL type systems. These areas would be logical outgrowths of our research and development effort to meet strategic requirements.

Nuclear power is extremely attractive because large amounts of energy can be obtained from small amounts of fuel. The fissioning of 1 pound of U^{235} liberates heat equivalent to that liberated in the combustion of 1,700,000 pounds of gasoline. The problem, of course, is the harnessing of this energy in a useful and acceptable aircraft propulsion system. The dimensions of the problem may be illustrated by comparison to the large land or naval reactor systems which are getting to be almost commonplace. To get these systems down to feasible aircraft applications would require something like a factor of 40 improvements in power and weight parameters. To achieve this kind of improvement, it is necessary to go to high density compact reactor systems, advance the high temperature materials technology, and to take the maximum advantage of techniques in shielding which allow significant weight reductions.

As you undoubtedly have observed from the open literature, there are many combinations of cycles, powerplant types, and cooling mediums. All reactor systems are heat transfer machines, that is, the heat is generated in the fueled materials and transferred through container walls to a working fluid. For manned aircraft reactor systems, the powerplant types are restricted to the turbojet, turboprop, and fan. However, manned ramjet applications may someday be possible in future advanced concepts. Our interests have further centered around the turbojet application in support of the strategic mission requirements.

Through the process of design study and application analysis, interest in aircraft powerplants have narrowed to two types, the direct air cycle and the indirect cycle heat exchanges system. In the direct cycle the airflow from the compressor is passed directly through the reactor and expanded in the turbine. In the indirect system, heat is removed from the reactor by means of a liquid metal and transferred to the air by means of a heat exchanger or radiator. The direct cycle system is under development by the General Electric Co. at Evendale, Ohio, and at the Commission's National Reactor Testing Station. The longer range, more basic program for the indirect cycle system is under development by Pratt & Whitney near Middletown, Conn. The Oak Ridge National Laboratory is assisting in both approaches, furnishing support in research, applied development and testing.

The direct cycle development program is a joint Air Force and Atomic Energy Commission effort which has been underway since 1951. Much of the basic research and development work has been in the area of materials development and in the development and testing of reactor experiments. The first of these experiments, heat transfer reactor experiment No. 1, is shown in this slide. This experiment operated in January 1956. It was the first time a turbojet engine—a modified J–47—was operated on nuclear power. Shown here is the test facility with all of its test piping, air ducting, and facilities for both nuclear and chemical operation. At the left are the modified engines connected by ducts to the reactor located in the large central tank. The ground test equipment is mounted on a dual flatcar so that it can be drawn between the test and maintenance areas by a shielded locomotive shown at the extreme right. In this experiment approximately 150 hours of all nuclear operation was accumulated with at total energy output from nuclear sources of over 5,000 megawatt hours.

Reports on progress made since HTRE–1 testing are classified. However, I can assure you that continued progress has been made in the area of materials development and in the direction of testing flight-type reactor systems.

The next slide shows the GE testing area at the National Reactor Test Station in Idaho. (Elaborate on the facility details.)

The indirect cycle development program is a joint Air Force and AEC effort, and is being carried out by the Pratt & Whitney Aircraft Division of the United

Aircraft Corp. in the facilities shown here. This complex is known as the Connecticut Aircraft Nuclear Engine Laboratory—more commonly known as CANEL.

The CANEL site consists of about 1,100 acres and has an unpopulated exclusion radius from the nuclear facilities of about 1 mile. The present facilities include a 150,000-foot machine shop (foreground); an administration and engineering building (left front); a general laboratory for light work, such as metallurgy and chemistry (center front); a shop laboratory for experimental rig work and small-scale component development (right front); engine radiator development laboratories (left rear); a heat exchanger laboratory (right rear); pump and turbine laboratories (far right rear); and in the background a two-cell critical experiment facility. Under construction is a hot laboratory for the dissection and examination of materials and components irradiated in test reactors.

The Pratt & Whitney program is directed toward advancing the high temperature, indirect cycle technology and materials state-of-art for ultimate application to high performance systems. Encouraging progress in this program is being made in the areas of high temperature compatibility testing of liquid metal coolants with their containing materials, high temperature fuel element development, and liquid metal propulsion component development.

Having established to some extent the characteristics of the nuclear powerplants, let us now relate these powerplants to airplane design. In general, a nuclear airplane will differ from a conventional airplane in three areas:

First, it will not require chemical fuel to accomplish its mission. This feature adds a completely new dimension to performance considerations;

Second, it will have a gross weight variance of less than 20 percent during a given mission, compared to 50–70 percent for conventional aircraft; and

Third, it will have to contend with a new environment created by the radiation field associated with the nuclear powerplant.

What do these three differences mean to the airplane designer?

First of all, he can ignore practically all considerations of fuel imposed trades or limitations. Since a nuclear airplane carries little or no chemical fuel, one need not be concerned with payload-range trades, airborne refueling problems, optimum cruise control, volume considerations, fuel sequencing for balance, points of no return, or concern over landing under adverse weather and limited fuel conditions. By its inherent unlimited range characteristic, the nuclear airplane could spend nearly half of its life in the air, or 40,000 hours of operation over a 10-year period. Such an extremely high utilization rate obviously requires discrete consideration of the structural fatigue aspects.

In addition, the constant gross weight characteristic requires that structure be designed to carry its full weight all the time. The landing gear, for example, must be capable of routine landings at full gross weight. The braking system also must have increased capacity for the gross weight consideration. Further, absence of chemical fuel burnup does not provide for improved load factors with flight time, or improved altitude performance. The nuclear airplane will have essentially a constant cruise altitude. The distribution of the constant gross weight also introduces unique design considerations. Since the nuclear powerplant must have a radiation shield, there will be large concentrations of mass at discrete positions in the airplane.

We have a choice of two shielding concepts, the unit shield or the divided shield. While the unit shield is more desirable from the radiation point of view, it can be extremely heavy, and thereby reduce aircraft performance. By resorting to divided shielding, a significant reduction in total shield weight can be effected. This can be done by partially shielding the reactor, and placing the remaining shielding about the most sensitive element—the crew. Such a distribution of mass, however, creates unique inertia and pitching movement conditions to be handled by the flight control system, as well as a structure consideration resulting from the cantilevered mass of the crew compartment.

The procedure for obtaining minimum shield weight is dictated somewhat by powerplant location. If the powerplant and reactors are mounted on pods, the direct radiation beam impinges on both the rear and side of the crew compartment, thereby requiring considerable side shielding. Moving the crew compartment farther away reduces the slant angle, as well as the geometric distribution of radiation, and permits a reduction in total shield weight at the expense of structure weight. An airplane so designed would appear somewhat unusual by virtue of its elongated fuselage nose.

Our studies reveal that it is more preferable, however, to locate the reactor as close to the aircraft centerline as possible to present a minimum direct beam area at the crew compartment. Under these circumstances, a long nose is not an identifying prerequisite of the nuclear airplane.

In fact, our investigations indicate that it costs less weight to add more shielding than to extend the fuselage for the same reduction in radiation dose to the crew. In this case, aerodynamic and volume considerations will dictate the nose length before shielding considerations will. In addition, the centerline location of the reactor permits effective use of installed equipment and accouterments to augment the shielding.

The use of the divided shield to reduce weight has its disadvantages, however. By splitting the shield, the aircraft and its components are exposed to a significant amount of radiation, varying in intensity with location relative to the reactor. We know that radiation may cause embrittlement of seals and elastomers, gassing of hydraulic fluids, may cause gumming and loss of viscosity in lubricants, and deterioration of transistors and insulation in wiring. In addition, we know that the neutrons may induce radioactivity in the basic structure of the aircraft and its components and may affect the operation of the equipment and complicate maintenance of the system.

On the surface, this sounds like a fairly foreboding set of circumstances, However, we are able to design around these characteristics of nuclear propulsion. We have programs in being which have been encouraging in developing radiation-tolerant elastomers, radiation-resistant hydraulic fluids and lubricants. In many cases, the substitution of highly resistant materials for weak materials in equipment appears to be a satisfactory approach. Locating sensitive equipment inside or ahead of shielded areas effectively eliminates the problem of potential radiation damage. Sometimes critical components may be shielded to permit their unmodified use. Slight changes in the alloy specifications of structural materials, eliminating high neutron cross-section elements, combined with a redistribution of neutron-to-gamma leakage from the reactor, result in significant reductions in airframe activation. Aircraft fabricated from aluminum and titanium, for example, are between 50 and 100 times less sensitive to activation than steel aircraft.

These techniques have been developed and verified through dynamic testing in facilities such as NARF (the nuclear aircraft research facility) at Convair, Fort Worth, where we have irradiated numerous subsystems, materials, components, and assemblies under dynamic conditions similar to those anticipated in the nuclear aircraft. For example, the AN/ARC–34 UHF communication set, during irradiation tests, operated within specifications, while a fuel control unit failed due to silicon diode deterioration. This failure was corrected by circuit redesign and substitute of various tubes for the silicon diode.

All of these considerations I have just outlined indicate that the structure and components of the nuclear airplane must be given special attention to assure adequate strength and life, and that normal design techniques may not necessarily apply. Notwithstanding these features, and possible high gross weights, the high density characteristic of the aircraft will keep overall dimensions close to those of the conventional aircraft.

In addition to shielding and radiation damage considerations, the design of a nuclear airplane is influenced by maintenance and handling problems. Because of the highly radioactive powerplant, it becomes necessary to do a certain amount of maintenance with remotely operated equipment. The powerplant must be capable of being installed and withdrawn by such equipment.

Shown here is the remote control installation of the aircraft shield test reactor in the conventionally powered B–36 nuclear test airplane. This airplane, equipped with a shielded crew compartment, was utilized in extensive inflight shielding research over a 2-year period. The reactor was installed and removed remotely many times during the flight program with installation time averaging about 30 minutes. Installation and removal of a nuclear propulsion system in a nuclear airplane will require similar techniques. In addition, military subsystems and equipment may need to be of the modular design, plug-in variety for quick removal. Inspection plates, fluid fill and drain points, and all items which are radiation sensitive or which are otherwise frequently replaced, must be accessible to remote handling and viewing devices.

The problems of residual radioactivity may be greater within the powerplant than those related to ground handling of the aircraft itself. After the reactor has been in operation, shutting it down does not completely turn it off. The

residual activity from fission fragments trapped in the nuclear fuel is sufficient to melt the fuel or its container in a very short time if cooling is not provided to dissipate the heat. We refer to this heat as afterheat, and must provide for its removal immediately after powerplant shutdown. This removal may be accomplished in several ways, the simplest of which is to operate the powerplant engines using conventional fuel, or by driving the engines with their starters thus providing cooling air. Special ground equipment can take over from the airplane's built-in after-heat removal system once the airplane is in the hands of ground personnel.

I have talked a lot about the airplane. I should like to spend a few minutes talking about the crew. The applications we foresee for nuclear aircraft envision flights of great endurance. Individual flights of over 100 hours are expected to be fairly routine. Many people not closely associated with our program have expressed concern over the feasibility of confining four or five crew members in a volume smaller than the average kitchen for periods of 5 days and expecting them to function effectively.

Let me describe briefly the kind of crew compartment and its appointments that we envision.

First, our crew compartment will be extremely quiet and almost totally free of vibration. The thick radiation shielding will effectively shut out most external noise and the mass will dampen nearly all vibration. Crew members will, therefore, be able to converse at normal voice level. The climate will be of the shirt sleeve variety, and pressure suits will be totally unnecessary. A secluded rest area will contain two bunks, a galley, lavatory, and even entertainment equipment such as movies, hi-fi, and books. The color scheme will be chosen to give a feeling of spaciousness. All instruments and equipment necessary to perform the mission will be accessible from within the crew compartment.

We have conducted experiments in such a crew compartment. During these experiments, five Air Force personnel simulated a 5-day SAC mission, including all elements of a typical flight profile from takeoff, through bomb run and emergencies, to landing. These experiments were performed without a hitch.

In addition to these experiments, we gain confidence from previous endurance flights that have been made under less desirable conditions. The most recent of these flights was performed by two gentlemen named Cook and Timm, who flew continuously for over 1,400 hours in a light plane. Previously, there had been flights of over 500 hours duration, and many in excess of 100 hours.

I have touched on many of the facets to be considered in designing nuclear aircraft. Any one of them can be the subject of an extended discourse, and I have deliberately limited my remarks to cover the broad front. In concluding, however, I should like to emphasize that the various applications I discussed are actually feasible, in the light of our present technology. However, to make them practical requires a straightforward development program designed to solve our many design problems in a logical sequence. We are pursuing such a program, and are confident of our eventual success.

Nuclear Power for Aeronautics and Astronautics

(By Maj. Gen. D. J. Keirn, USAF, before Washington Chapter, Institute of Aeronautical Sciences, April 14, 1959)

Good evening, members of the Institute of Aeronautical Sciences and guests. This is the third time in the past few months that members of my staff and I have addressed an Institute of Aeronautical Sciences group on our work in developing nuclear reactors for aeronautical and astronautical applications. I am gratified at the interest you have shown, and I am especially pleased at having been invited to speak to you tonight.

Our programs are divided into two areas: One, the application of nuclear power to manned aircraft; the other, the development of nuclear powerplants for missiles and space applications. I have with me the officers who are directing these activities. My deputy, Colonel Armstrong, who is also chief of my missiles project branch, will give you details of work on the nuclear propulsion of missiles and other nuclear-power applications to space vehicles, and Colonel Tesch, chief of my aircraft projects branch, will discuss details of the manned aircraft effort.

Interest in nuclear-powered flight has been significantly stimulated during the past year as a result of the increased emphasis now placed on our country's posture in scientific achievement. This emphasis on technical progress has resulted in many suggested programs to accelerate the ANP program in an effort to beat the Russians to first nuclear flight. Many of these suggestions would comprise a mere demonstration of nuclear-powered flight for psychological purposes and without regard for tangible usefulness. In regard to our manned aircraft program, we believe a more effective use of our national resources requires that we direct our efforts toward producing an operationally useful nuclear-powered airplane. Therefore, rather than pursue a program of the demonstration variety, the Air Force is pursuing a program leading toward the objective of a useful weapon. We have just recently completed a competition to select a contractor for the design of a nuclear-powered developmental airplane having weapon system design characteristics. The Convair Aircraft Division of General Dynamics Corp. has been selected to accomplish this task.

We call it a developmental airplane because it would be used as a tool for powerplant proof-testing and for solving the many design problems associated with achieving a practical weapon system. Colonel Tesch will discuss this program and some of the peculiar design considerations inherent in nuclear powered aircraft.

In our missile programs, we have three main lines of endeavor. These projects are, at present, directed toward demonstration of feasibility. One is to develop small nuclear-power devices to provide electrical power for satellites or space vehicles. This is Project SNAP. The Air Force and the Atomic Energy Commission are working together with the National Aeronautics and Space Agency to develop several of these small long-life nuclear-power sources. One of the "proof of principle" units in this, developed in our SNAP III project, we demonstrated before the President in January. You may have read about it in the paper. Colonel Armstrong will tell you more about it.

The second line of endeavor is the development of a nuclear rocket engine, our ROVER project. This effort is centered at the Los Alamos Scientific Laboratory.

Our third endeavor is our PLUTO project, which is pointing toward the development of a nuclear ramjet. This project may make possible a formidable air breathing missile system with extreme speed at low altitude, long range and a high payload. Effort on this project is centered at the E. O. Lawrence Radiation Laboratory at Livermore, Calif.

The details of these missile projects will be covered by Colonel Armstrong. Colonel Armstrong will lead off, and Colonel Tesch will follow with a discussion of the manned aircraft program.

The Next 10 Years in Manned Aircraft

Remarks by Lt. Gen. Roscoe C. Wilson, Deputy Chief of Staff, Development, Headquarters, USAF, before the Aviation Writers Association Convention, Washington Hotel, Washington, D.C., May 15, 1959

I understand that when Gen. Don Putt spoke to you at your annual dinner in Houston last summer he stated that never had so many who knew so much about aviation listened to a speaker who could say so little that is news.

I am in a somewhat similar position.

But be that as it may I am glad to discuss with you my impressions of what to expect in manned aircraft in the Air Force during the next 10-year period.

I do not know of a more appropriate audience to speak to than members of the Aviation Writers Association. You perform a great service in keeping the public informed on aviation matters and there is no doubt that you have contributed to the tremendous growth in aviation in the past and will continue to do so in the future.

After 13 years, the aircraft nuclear propulsion research and development effort supported jointly by the Air Force and the Atomic Energy Commission has successfully passed many important technical milestones.

Through the process of design study and applications analysis interest in aircraft powerplants have narrowed to two types—the direct air cycle and the indirect liquid metal cycle.

In the direct, the air flows from the engine intake, through the compressor, thence directly through the reactor where it is heated and is then expanded through the turbine and flows out as a jetstream.

In the indirect cycle the reactor heats a liquid metal which flows through a closed system. The air is heated by flowing through a heat exchanger.

The indirect cycle has many advantages over the direct, but is considerably further away for aircraft application.

The direct cycle turbojet system is under development by the General Electric Co. at Evendale, Ohio, and at the National Reactor Testing Station in Idaho.

Pratt & Whitney is engaged in the longer range indirect cycle program at Middletown, Conn.

The Oak Ridge National Laboratory is active in both approaches, furnishing support in research, development, and testing areas.

The General Electric contract for the direct cycle system is for the development of a prototype propulsion-system model—the actual hardware now within the present state of the art. As far back as January 1956 a modified J–47 engine was successfully operated on nuclear power. Approximately 150 hours of all-nuclear operation has been accumulated.

I can assure you that continued progress has been made since 1956 but for security reasons I cannot go into details.

So much for the powerplant.

Now let us talk briefly about the airframe.

Following competition between Lockheed and Convair, the Fort Worth Division of Convair was declared winner and authorized to work with General Electric in the initial design of a prototype nuclear-powered airframe. We therefore are now ready to embark on a program to produce a subsonic nuclear-powered airplane which will be the prototype of a future weapon system.

Our decision to proceed was made after assurance had been obtained through exhaustive studies and tests that the shielding problem is no longer a hindrance to delay the construction of a prototype aircraft. This had been our final obstacle.

Now why does the Air Force want a subsonic nuclear-propelled aircraft when we have 2,000-mile-per-hour, high-altitude bombers under development?

We foresee the need for a continuously airborne missile launcher and low-level penetration airplane. We call this our CAMAL requirement.

Nuclear power will give the CAMAL bomber unlimited range and tremendous endurance, limited only by crew fatigue.

Each airplane can remain airborne for a week at a time or more permitting the Strategic Air Command to keep a large percentage of its bombers continuously airborne.

These bombers, carrying full armament and always ready for instant retaliatory action, will be ale to cruise anywhere in the world, out of reach of sudden destruction on the ground by surprise missile attack or sabotage.

Each airplane can carry several long-range ballistic missiles to be launched against enemy targets long before the airplane penetrates the enemy's defense perimeter. In addition, the CAMAL bomber can carry high-yield bombs or short-range missiles.

Nuclear power will enable it to penetrate enemy territory at low altitude and high speed undetected by long-range radars and thus relatively secure from interception by enemy fighters. The CAMAL could start this penetration from any direction and follow an evasive path to any target, without the limitation of range. It could place over the enemy's heartland men to exercise judgment and follow up missile attacks by aerial bombardment either of targets left untouched by the missiles, or new, previously unsuspected targets.

Its value as an antisubmarine weapon is obvious.

The design of the airframe for the CAMAL bomber is no longer a matter of research directed at achieving technological breakthroughs. The necessary state of the art has been established. The effects of atomic radiation on aircraft equipment are now sufficiently understood to enable us to proceed with a prototype aircraft.

The shielding problem for nuclear airplanes has been solved.

We now know how to design effective airborne shields and how to predict their performance.

Our progress has been such that we can confidently expect an airworthy nuclear powerplant to become available in about the length of time required to build a prototype airplane.

You might be interested also in knowing the CAMAL airplane will not necessarily be any larger than the current B–52, also that it will be designed to operate off the same runway lengths as the B–52.

The 4- or 5-man crews of such an aircraft will operate in a quiet and almost vibrationless cabin.

They will be able to converse in normal voice tones and enjoy shirtsleeve environment as the cabin would be designed to eliminate pressure suits.

A secluded rest area will be provided which will include beds, lavatory, kitchen, and even entertainment such as hi-fi, movies, and books.

We have conducted experiments in such a crew compartment where five Air Force personnel simulated a 5-day SAC mission, including all elements of typical flight profile from takeoff, through bomb run and emergencies, to land again. It was performed without a hitch.

AIR DEFENSE

Air breathing missiles and bombers will continue to be a threat during the next 10-year period. We can expect such weapons to improve in quality although they probably will decrease in numbers as ballistic missiles become more numerous and effective.

The first step in providing STOL is the boundary layer control (BLC) C–130, and we are now looking into the feasibility of a VTOL transport.

In these times of routine supersonic flight, a companion supersonic transport to facilitate rapid deployment of ground personnel and to provide timely logistic support is a must. This type of an aircraft will be developed for both civilian and military usage. Supersonic flight for transports is considered the next order of development and can be expected to precede the pure VTOL transport.

In conclusion, I hope I have made it clear that the USAF must depend upon manned aircraft for the foreseeable future, and has laid down a concrete program for their development. Unmanned missile systems may change the use and emphasis upon manned weapons systems but, so far as we can see into the future will never render them obsolete.

REMARKS BY REPRESENTATIVE MELVIN PRICE, CHAIRMAN OF THE RESEARCH AND DEVELOPMENT SUBCOMMITTEE, JOINT COMMITTEE ON ATOMIC ENERGY, PREPARED FOR DELIVERY BEFORE AIRCRAFT LUNCHEON CLUB, WASHINGTON, D.C., TUESDAY, JUNE 9, 1959

PROSPECTS FOR THE NUCLEAR POWERED AIRCRAFT

It is a pleasure to have been asked to join you here at your luncheon today. I understand your membership is made up of representatives of companies manufacturing aircraft, missiles, rockets, space vehicles, and other means of propulsion for air and space travel. In such professional company I will not propose to lecture you on your own medium, but rather will confine myself to expressing a few opinions of a layman who has some acquaintance with the field in which all of you are working.

It is significant, I think, that you have retained the title of Aircraft Luncheon Group in this year when we are hearing so much about missiles and rockets. Without disparaging their importance, I think that it is necessary for us to realize that there is—and will be—for some years to come, a continuing need for aircraft to perform duties which missiles and rockets are not equipped or designed to perform.

Recognizing that aircraft will be with us for some time, I would like to give you a few of my own impressions about the program currently being undertaken to develop a specialized kind of aircraft, propelled by nuclear power. While it might be truly said that the nuclear powered aircraft is an advanced concept opening up new frontiers, it can also be said that it is a logical projection of aircraft development, with one important dimension added. This dimension is the promise of almost unlimited range which will permit it to do many jobs which are now difficult if not impossible with conventional chemically powered aircraft. As everyone can readily see, this new capability opens the door to all sorts of possibilities with regard to potential military and later, civilian uses.

The nuclear-powered plane, despite its advanced technical status, has been with us for over a dozen years now and has been the object of intense interest

and support by the Joint Committee on Atomic Energy of the Congress. The Committee has particularly pressed, all along, for centralized direction of the technical program so that the working scientists and engineers in the field would not be subjected to conflicting guidance from several quarters and would have a clear idea of program objectives. Committee support has historically been a bipartisan affair, and I am often reminded of the major role which my late friend and colleague on the Committee, Carl Hinshaw of California, played in pressing for progress on this project.

The idea of a nuclear-powered plane was first brought forward in the old NEPA program back in 1946 in which the Fairchild Engineering & Aircraft Co. was asked by the Air Force to undertake a study of possibilities, together with scientists at Oak Ridge National Laboratory. By 1950 the feasibility of such an aircraft had been effectively demonstrated and in 1951, the NEPA program had given way to a program aimed at developing an appropriate propulsion system. The General Electric Co. was brought into the picture as prime contractor to the Air Force and AEC, and was asked to develop a direct cycle system.

At the same time Convair was asked to initiate a program at their Fort Worth plant, designed to test out shielding and flight problems with a reactor. Somewhat later, Pratt & Whitney was asked to start work on an indirect cycle propulsion system and Lockheed was asked to initiate an airframe program paralleling the one at Convair.

By 1953 the direct cycle propulsion system had been developed to a point where the Air Force proposed to try it out in a flying test bed, utilizing a modification of the B–36 bomber. The technical people in the field now feel that if this program had gone forward vigorously, the chances are good that we would have had such a flying test bed in 1957.

You may remember this B–36 flying test bed concept was effectively spiked by Secretary Wilson in 1953 in his famous "Shitepoke" statement and the whole ANP program was virtually canceled. Only the most strenuous efforts on the part of the program's advocates and the Joint Committee kept the project alive, albeit on a clearly reduced basis.

Then in 1955 the Air Force built up another head of stream for a high performance nuclear bomber, including a complete weapons system, basing its proposals on promising technical developments to that point. This was approved and the large scale project was begun, only to fall of its own weight in 1957. The disapproval of this concept in 1957 by the Defense Department had unfortunate ramifications far transcending the mere cancellation of the high performance idea.

The effect of this action, which we can still feel today, was to place the whole concept of effective nuclear flight in doubt in the minds of many people and this period of disenchantment reversed the impetus in Washington toward pressing ahead to a successful resolution of the technical problems involved. This was ironic because the technical development was proceeding on schedule, including the successful testing of experimental reactors.

In the fall of 1957 a more realistic proposal was brought forward in the Pentagon to proceed with a flying test bed, utilizing a modified conventional plane as the carrier of the nuclear propulsion system. This proposal, which was based on sound technical considerations, was on its way to approval by the Secretary of Defense until the intervention of two new and important factors.

One of these was the emergence of a special panel set up by the President's Scientific Adviser, Dr. Killian, who raised serious questions about the readiness of the project technically to go forward to a prototype flight program. It is interesting to note that this "expediting" group, whose review of the project was cursory in nature, intervened with the Defense Department, in an "advisory" capacity before the Defense Department itself had made its recommendation to the President.

The second factor which emerged at this time was a sudden renewal of interest in the ANP program by the Navy, who took sharp issue within the Defense Department on the dominant role which had been assumed by the Air Force in the program. While I am all for active Navy participation in the program, together with the Air Force, this particular action by the Navy created confusion within the Defense Department as to appropriate assignment of responsibilities. Before the smoke had cleared, the Killian committee had gone to work and the flying test bed concept once again bit the dust.

Back in the fall of 1957, I wrote a letter to the President, expressing my strong support for going forward with an early flight program, utilizing the

flying test bed concept which had been proposed within the Department of Defense. I urged that we proceed with such a program, not only for purposes of getting on with the development of a militarily useful aircraft, but also as a demonstration of America's scientific capabilities in light of the Russian scientific challenge. I believed then, as I believe now, that the Russians themselves are making significant progress in the field of nuclear powered aircraft, and I think there is a good chance they will actually put such a plane in the air this year.

The President's reply to my letter, which arrived 4 months later, in March of 1958, took note of my arguments but explained that as far as the executive branch was concerned, initiation of a flight program would at that time not be productive in the development of a "useful" aircraft, and that further research and development would be required.

In an attempt to meet this question of usefulness which had been raised by the President, the Air Force last year established a requirement for the so-called CAMAL sysem, which called for the construction of a new prototype aircraft capable of serving as an initial test vehicle and later, with any necessary modifications in the design, as an operational military aircraft. While no final approval of this requirement has yet been made by the Defense Department, plans are proceeding and Convair has recently been selected in a competition with Lockheed, to develop designs for the airframe.

The mission of the CAMAL airplane is to serve as a continuous airborne and alert missile-carrying bomber of long range, with a low level penetration capability. This "on-the-deck" capability where it can stay out of range of the enemy's radar detection systems, is one of its chief advantages over conventional chemical aircraft whose large fuel consumption at low altitudes seriously reduce their range.

At the same time, the Navy has asked both General Electric and Pratt & Whitney to proceed with studies of a turboprop propulsion system for utilization in a large flying boat for antisubmarine and other patrol duty. The Navy proposes to put this system in the Princess flying boat, developed by Saunders-Roe in England.

I think it must be evident from the brief history I have described to you, that the ANP program has been beset by a multitude of problems since its inception. In my opinion these problems have not been so much a question of technical progress, which has in general been good, but rather involve the problems of ill-defined objectives and administrative indecision. Despite constant prodding by the Joint Committee over the years, these roadblocks have had a tendency of lingering on, to the detriment of all. Particularly vexing, afer 12 long years, is the fact that the program still has no firm target date for first flight and our scientists and engineers in the field still don't know where they stand as to the future prospects for the program. This latter factor has for some time been a bad morale problem in the field, as you can well imagine.

But beyond this, I have had the feeling all along that there has been considerable confusion over this question of so-called usefulness, which I mentioned earlier. I think it is high time that we nail down, once and for all, what is meant by "usefulness" and then get on with the job.

From my own point of view, and that of the working engineers in the field, the most useful thing we can do at this point is to test out the propulsion system in actual flight as soon as possible. No one has ever pretended that this first flight would involve a fully operational military aircraft. Far from it, this first flight, in line with historical precedent, would be a distinctly limited affair aimed specifically at providing information which is vital to subsequent development of a fully operational aircraft. It is my understanding that we are in fact technically ready to proceed with this limited first flight, and further delay will only put off the time when we reach a fully operational capability. Unless I am sadly mistaken, I think this concept is finally percolating through to those who have responsibility for making this decision on a flight program. I hope so.

Any decision to go ahead with a flight program will, of necessity, require some upward adjustment in the present ANP budget from its present level of $150 million per year. This is indeed a lot of money and my main concern is that we don't waste our investment at the taxpayer's expense.

Early last month a critical series of discussions were held between representatives of the Defense Department and AEC with regard to possibilities for development of a flight program. I gather the consensus of these sessions

was that a draft paper should be prepared for presentation to the President, recommending the initiation of a flight program.

I believe this paper would have gone forward to the President except for the untimely death of Secretary Quarles. I would like to state parenthetically that despite our policy differences, I had a warm personal regard for Mr. Quarles and considered him a good friend. He was a man of high personal integrity and the Nation has lost a fine and able public servant.

Responsibility at the Defense Department for the ANP project has, since Mr. Quarles' departure from the scene, been vested in Dr. Herbert York, Assistant Secretary of Defense for Research and Engineering. Members of the committee got together informally with Dr. York and Mr. McCone, Chairman of the AEC, a couple of weeks ago to discuss the progress of the program and the question of whether or not plans are being made to go forward with the prototype flight program. At that time, we agreed that the Defense Department and AEC would report to the committee some time this month on what action is to be taken.

I am informed that Dr. York, Mr. McCone, and other representatives of the two Government agencies, have been giving this matter a good deal of their personal attention since our meeting and I am hopeful that we will soon have a clearer idea of which way the program is to go.

I hope and I trust that budgetary considerations will not be overriding, in this regard, and that due account will be taken of the technical readiness of the project to move forward to actual flight. A further "stretch out" of the schedule would, in my opinion, not only not save money for the American taxpayer, but would seriously jeopardize attainment of national needs in this field.

Thank you again for inviting me to join you here today. It has been a great pleasure to be with you.

1958

REMARKS BY MAJ. D. J. KEIRN, ASSISTANT DEPUTY CHIEF OF STAFF, DEVELOPMENT FOR NUCLEAR SYSTEMS, FIFTH SEMIANNUAL ANP SHIELDING INFORMATION MEETING, ATLANTA, GA., MAY 14, 1958

Mr. Tostmaster, members of the shielding symposium, and guests, I am very honored that our host for this symposium, the Lockheed Co., has invited me to speak to you this evening, I am particularly gratified to have the opportunity to speak to this group whose efforts in the shielding program will play such a major part in the ultimate success of the aircraft nuclear propulsion program.

You will note from the biographical sketch of my prior activities that I am not a member of the Toastmasters Club, Inc. My customary speeches are unsolicited. My last solicited speech was an after-luncheon speech in Milwaukee in 1938. On this occasion there was keen competition for the speaker's rostrum. The principal speaker was a Governor of a neighboring State who was commencing his campaign for President. His speech was long and eloquent. I confined my remarks on the occasion to an expression of appreciation for the city's hospitality, inasmuch as I was a guest, the quality of the luncheon, and the lack in the menu of the product that made their city famous. My speech was short, but it was fruitful. I was supplied immediately with the missing product. The Governor, I think, is still running. And this brings me to the purpose of my speech tonight, the lack of a product, delivery of which will make some or all of you famous, a lightweight aircraft shield. Will some of you gentlemen supply it?

It has been suggested that I might offer some of my views with regard to the future of nuclear-powered aircraft. I think it is probably safer to predict the outcome of the world's series than to predict a specific event in ANP.

Nevertheless, we all bet on our favorite ball club, and I will lay a wager on where ANP is going. Before I do so, however, I would like to make a few remarks of a more current nature, and particularly with regard to some of the more fundamental activities like your own upon which the future of ANP is entirely dependent.

I have always felt that the two basic problems in nuclear-powered flight are, first, the high temperature material problems of the reactor and, second, shielding. Since the group here is primarily interested in shielding, I would like to examine the major aspects of our shielding effort. In the popular mind,

shielding has caused more concern than the problem of reactor materials. For many years it was felt by many people that shielding was the sole roadblock to nuclear flight. Today, I think we may safely say that shielding methods and analysis have advanced to the point where our major concern is reactor materials. Much of the credit for this advancement belongs to the people in this room. Much of the basic shielding progresss made to date has been accomplished at the Oak Ridge National Laboratory, using the excellent facilities there, including the Tower Shielding Facility. A great deal of the practical applications of shielding to flight-type problems have been attacked by the group at the Nuclear Aircraft Research Facility operated by Convair. The major achievement of this group is, of course, the nuclear test airplane and the wealth of data which it produced. Many of the applied and practical shielding problems concerned with propulsion unit construction have been solved by the group at GE. Much of this is history now, and more and more people and agencies are contributing to our science every day, as a glance at the agenda for this meeting will confirm. It is sometimes enlightening and helpful to stand back from the small details and frustrations of everyday research and experimentation to ask ourselves just what we are striving for in the ANP shielding program.

I believe that our major goal is best stated as a design technology. With a fully developed design technology, we will be able to predict shielding results as we now do in other technologies like aerodynamics and mechanical engineering. We should be able, sometimes in the not too distant future, to design and predict a shield both of unit and divided type to a high degree of accuracy in all its aspects of weight and resultant dose. I cannot predict with any certainty when we will reach this state of art, but I can assure you that we must reach this goal in order to build the best and most useful nuclear-powered vehicle. We must continue our search for better shielding materials, more accurate experimental techniques, and, most important of all, accurate design methods. Perhaps the application of the Monte Carlo method using some of the large new electronic computers will assist materially in helping to answer our problem. However, I do not expect perfection.

Regardless of the degree of accuracy which we will develop in these design methods, I feel that, as in the case of aerodynamics and mechanical design, we will always be faced with factors of uncertainty, and we will in all probability find ourselves conducting tests on specific designs and tailoring these specific designs to obtain the most effective shield. With all our knowledge of structural design, we still employ static testing techniques for airframes, dynamic testing of rotating components, from which tests we make empirical modifications in order to meet our expected performance. This is particularly true in the aircraft business where the peak of perfection is best illustrated by the old poem about the one-horse shay. We want every part to live its expected lifetime, we would like every part to fail immediately thereafter. While it is true that making a part heavier does not always make it stronger, I know of no case in which a part which is stronger than need be, cannot be made lighter.

I think it is only appropriate that I say a word also about some of our problems other than the technical ones. The problems I refer to would probably belong to the sales department in the normal industrial organization. Two of of them have to do with product sales: First, the problem of stimulating public interest, and of creating a receptive attitude on the part of the customer, and, second, the problem of convincing the board of directors that our product is good, salable, and that we need more money to develop it. In our case, of course, our customers are the military services and possibly commercial airlines, and our board of directors is the Atomic Energy Commission and the Department of Defense. In the sales department, our progress has been disappointingly slow. Initially, 12 years ago, our customers thought we were crazy and that a nuclear-powered airplane could not be built. Our board of directors was persuaded to take a look, which it did by appointing an investigating committee. This committee was later known as Lexington project. These investigators concluded that indeed such an airplane could be built, but they also cautioned that the product would be costly and that they were skeptical about its utility. So our directors said to us, you must show us how this product can be used. This was 10 years ago; our sales department has been at work on this problem ever since. We have been pressed to show why our product cannot be better in all respects than the best forecast for other products in each of their individual virtues. We made some bold efforts, but we have not yet been able to outprophesy the prophecies of advocates of chemically propelled aircraft.

Today we stand much closer to our goals. We have had to give a little; our customers have given a little. It appears that we are on the verge of offering an acceptable product. While I cannot be specific, with regard to performance, we are now offering a strategic bomber capable of remaining in the air for long periods of time, acting as a nomad roaming force, relatively invulnerable to detection and interdiction, and capable of launching immediate retaliatory blows from many directions against any aggressor. Such a deterrent force serves our purpose of securing peace for it assures an aggressor of losing any war he starts because in this day and age of nuclear warfare no one wins as long as an effective counterblow can be launched.

I know that you are interested in the problems that face us in getting more effort into the ANP program, and I would like to address myself for a moment to the problems as we have to face them on the Washington scene. Technology is advancing at such a rapid rate in so many fields that it is hard to distinguish their relative importances, or decide the apportionment of funds to provide the optimum overall advancement. As a technology becomes more advanced, each incremental advance becomes more and more costly. Aircraft that cost $100,000 in World War II cost $5 million today. This is not solely an inflation in wages and materials costs—the airplanes I refer to are different, more complex, have required more scientific manpower in their design and production. So while the dollars available to our Government to create new weapons and to maintain our forces in being may bear a certain relationship to our gross national product, the costs of providing new weapon systems is increasing at a very much greater rate. We must then be very discriminative about which systems we pursue to completion, and we must bend all our effort to avoid unnecessary duplication, and to so order our technical activities as to produce the most for the dollar. This must apply to all of us—those of us on the management end, and those of us in the laboratory, and shop. Shortage of dollars does not always imply low priority or low importance.

I have confined my remarks so far to the manned aircraft program. However, as you know the ANP program encompasses nuclear propulsion devices for rockets, ramjets, and nuclear auxiliary powerplants for satellites or space vehicles. Our sales department is not nearly in so deep water on these ventures as in the manned airplane program; in fact, enthusiasm is high for anything stamped "space vehicle" or "To be used with a space vehicle." Those of you involved in the program of providing adequate shielding for manned aircraft will in time find yourselves equally concerned with shielding in rockets and space vehicles. I have just recently appeared before the House Select Committee on Astronautics and Space Technology which is concerning itself about the organization to manage our space programs. The Senate also, as you know, has a committee reviewing the same problems. With all of the attention being focused on this area, it would appear that someone will be in space before very long.

And now to some prophecies: Where is ANP going? As I indicated earlier, we believe now we can produce a nuclear-powered strategic bomber having a great potential utility. This, I think, will be our first step. I do not regard this as the end of the line. I believe when we have an airplane in the air, we will find many ways of doing things better and such an airplane will be followed by aircraft having much superior performance and greater utility. I do not like to forecast performance, but I do not see why nuclear aircraft should not achieve performance comparable to any that can be achieved with chemical aircraft and still possess the unlimited range capability of the nuclear aircraft. This will require improved performance in materials and reasonable reduction in weights, and I am counting on moderate improvement in shield weights as we learn better how to predict effects and design for minimum weights. I anticipate some improvement in aerodynamics, improvements in lift over drag ratios for supersonic aircraft, so that long-range flights at supersonic speeds will be commonplace.

I have heard the question asked of the missilemen: "Could you transport a payload from New York to London in 20 minutes?" Their answer has been "Yes." The problems in such achievement are great but without going into a dissertation on respective efficiences, the efficiency of rocket transport from a fuel-payload standpoint is not as bad as has been commonly supposed. I am still somewhat doubtful as to whether cutting the time of flight from New York to

London from 2 hours by plane to 20 minutes by rocket warrants the complexities involved in the rocket system particularly the reentry and landing problem. I have used a 2-hour flight time by plane for comparison because it seems to me a reasonable expectancy to achieve the 2-hour timetable in a supersonic nuclear powered airplane. Give me an aircraft of improved L D, but within the realm of present thinking, improved reactor out temperatures also not outside the realm of reason, a reasonable improvement in shielding, and let me not forget the dollars, and I think we could give you such an airplane. I haven't any orders from the airlines as yet you understand, but then they did not believe in turbojet transports 15 years ago. When will we have such an airplane? You might plot a graph of aircraft speed versus time and make a fair estimate. I am reminded of a friend of mine who was visiting the Armed Forces Day show at Andrews Air Force Base near Washington some 3 or 4 years ago. He was shown an Air Force fighter and told the performance was secret. My friend said, "It is probably capable of such and such a speed in level flight." The Air Force officer who was conducting him through the exhibit said, "Sir, where did you get those figures, they are supposed to be secret. Can you tell me where you got them?" My friend replied, "I have simply plotted chart of published speeds against dates accomplished. The projection of this curve shows that this is the date for that speed."

I cannot stop forecasting without getting into the space travel business. As I mentioned earlier the ANP program does encompass a program to develop nuclear rockets and nuclear auxiliary powerplants for satellites or space vehicles. It is my feeling that exploration of space in unmanned as well as manned vehicles will be topical matter in the papers before you and I are too old to read. I believe nuclear power will play a big part in this space exploration, but that is a speech in itself and I will close my remarks here. I will be very happy to respond to questions if that is your wish.

Tests of a Direct Cycle Nuclear Turbojet System

International Conference on the Peaceful Uses of Atomic Energy, September 1–13, 1958, Geneva, Switzerland

Submitted by D. Roy Shoults, General Manager, Aircraft Nuclear Propulsion Department, the General Electric Co., U.S.A.

Development of an aircraft nuclear propulsion system is complex because this type of system, to be useful, requires generation of large amounts of heat from a nuclear reactor of very small volume. This heat source must be combined with proper turbomachinery, controls, accessories, and shielding to protect aircraft components, cargo and passengers, and crew from nuclear radiation. All these requirements must be provided within very stringent weight limitations.

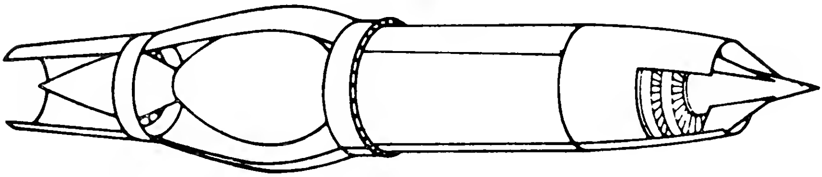
Several aircraft nuclear propulsion systems are considered possible. The direct-air-cycle turbojet powerplant is one nuclear propulsion system that is feasible. The General Electric Co., under contract to the U.S. Government, has been working on such a nuclear propulsion system since 1951. This paper recounts some of the highlights of this work.

Prior to the HTRE No. 1 tests that shall be described, design and analysis studies and component tests had indicated feasibility and had shown also that vital performance and operational information could be obtained only by a complete system test that would provide the following basic information:

1. Control response of the reactor and its relationship to turbojet engine control.
2. Integrated performance of the reatcor and turbojet engine in the powerplant system.
3. Proof that overheating in portions of the reactor would not lead to local flow starvation and progressive overheating and failure.
4. Determination of what problems might exist that were not anticipated.
5. Demonstration of integrity and life of key components of the system.
6. Development and demonstration of ability to carry out extensive remote handling of radioactive components.

The schematic illustration (fig. 1) is of a reactor, a shield, and a turbojet engine in a possible configuration of a nuclear powerplant for flight. The same

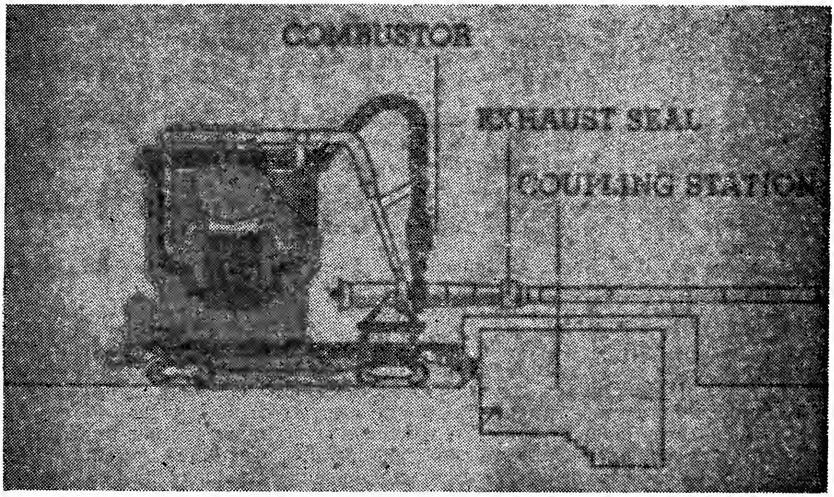
FIGURE 1



cycle was used in the 1956 test, called heat transfer reactor experiment No. 1, and propulsive thrust was provided by sending atmospheric air from the compressor directly through the reactor (thus the designation "direct air cycle").

A schematic diagram of the heat transfer reactor experiment No. 1 power system and the test assembly are shown in figure 2. The entire assembly is mounted on a railroad-car-type dolly to provide transportation from the shop area to the test pad. The engine is a modified General Electric designed J47 turbojet engine.

FIGURE 2



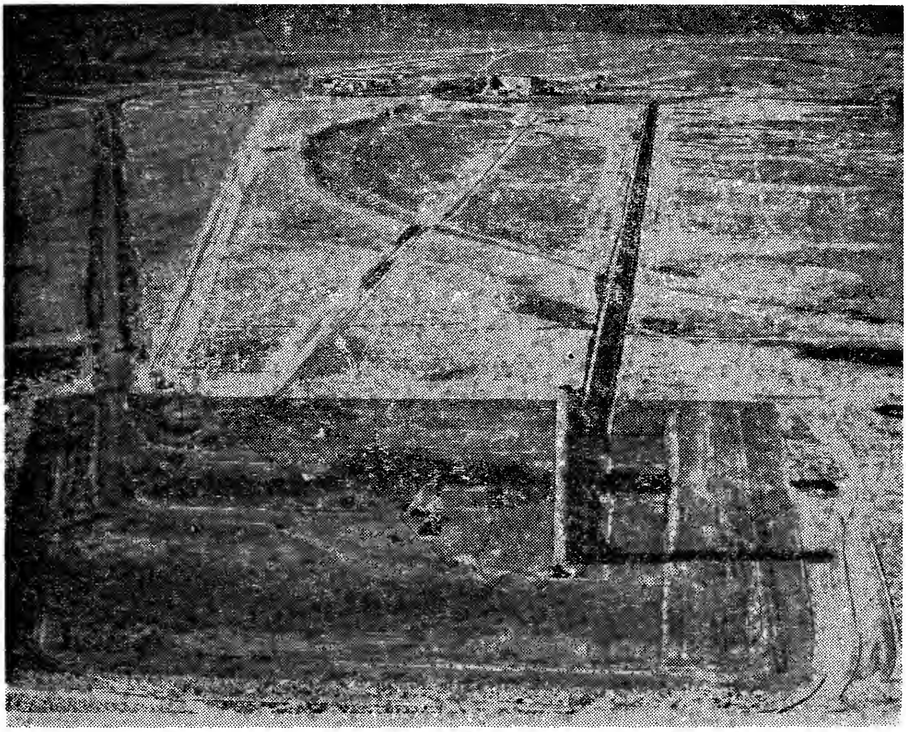
The reactor is air cooled and water moderated and contains metallic fuel elements. Fission is caused mainly by thermal neutrons. The shield consists of water, steel, and lead, and is designed to reduce radiation to a very low level for convenience in developmental operation. Our aircraft-type shields, in general, will be much smaller and will be made of different materials.

Air enters the turbojet engine, is compressed, and collected in a scroll and ducted to a manifold on top of the shield tank. The air passes through the shield in a number of parallel ducts and enters the air plenum chamber above the reactor. The air passes through the reactor, is heated, and enters another plenum chamber at the reactor exit. From there the air returns to the engine, turns the turbine that drives the engine compressor, and is exhausted through the jet nozzle. The combustion chambers, in which standard petroleum distillate fuels are burned, were removed from their normal location at the middle of the engine and were replaced with a combustion system in the external ducting.

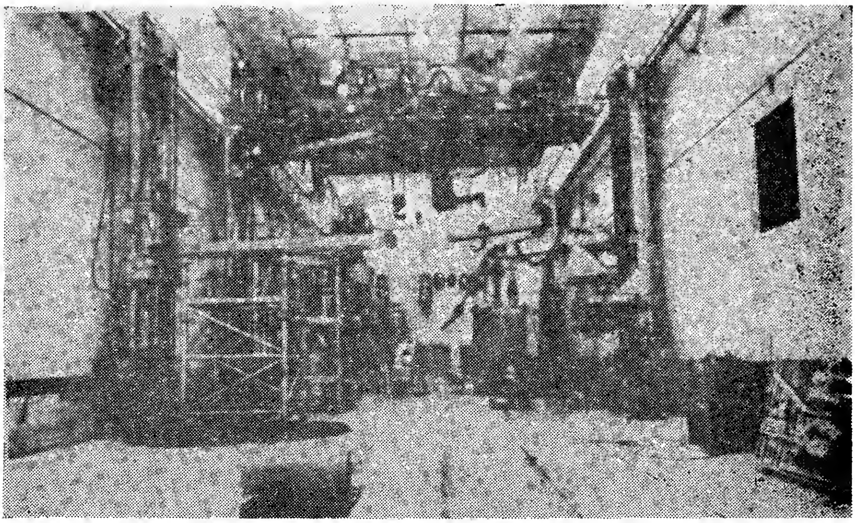
The air, which is necessary to provide propulsive thrust, may be heated either as it passes through the reactor or by burning jet fuel in the burner cans. A J73 engine combustion system was used because it is larger and of newer design than that in the J47 engine. In actual operation, the engine is started completely on turbojet fuel.

As the air from the compressor flows through the reactor, the reactor is brought slowly up to power and adds heat to the air stream in gradually increasing quantities. To maintain a constant air temperature at the turbine inlet the heat added to the air by the combustion system is gradually diminished until the engine is operating entirely on nuclear power.

This test was conducted at an isolated site at the U.S. Government's National Reactor Testing Station in Idaho. The function of the station, known as Aircraft Nuclear Propulsion Idaho Test Station, is the testing of propulsion systems. The isolation of the site ensures positive safety for the public during the early tests. The Idaho test station, shown in figure 3, is divided into three sections: an administration area, a shop area, and a test area. A railroad track system connects the areas.

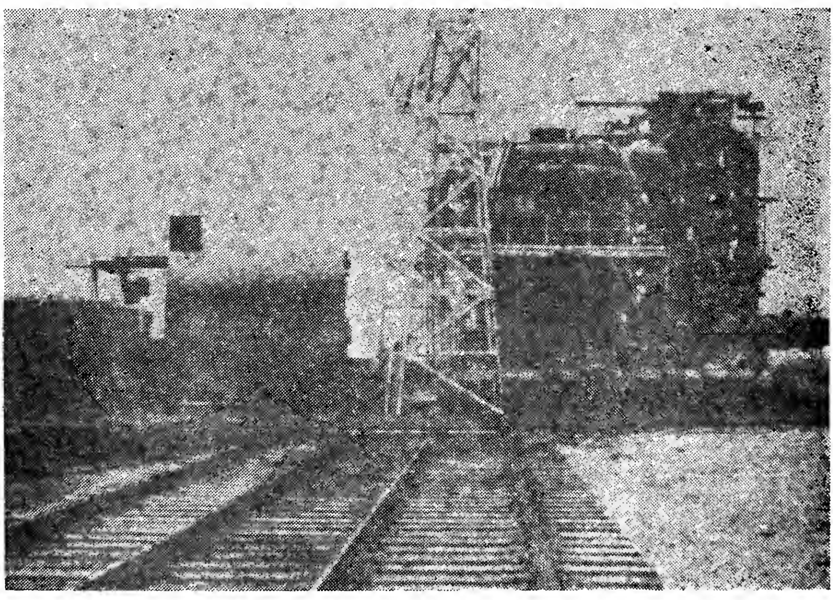


In the shop area the assembly can be put together before test and maintained after test. Engine overhaul and assembly of a powerplant is done in a cold shop, so named because there is no radioactivity present in the shop. This is contrasted to what we call a "hot" shop, shown in figure 4. The "hot" shop is a room 50 feet wide, 160 feet long, and 60 feet high. The concrete walls of this room are 7 feet thick. Radioactive components are maintained and disassembled in this room by mechanical manipulators that are controlled from the outside of the concrete walls. The manipulators shown can reach anywhere in the shop and can lift 500 to 3,000 pounds.



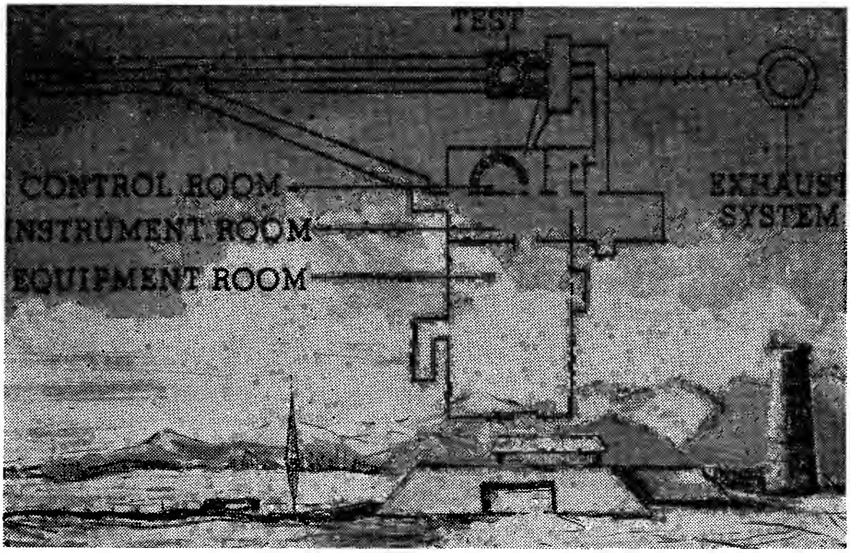
The powerplant was assembled on a railroad-type flatcar in the "hot" shop and then was moved to the engine test pad 6,000 feet away by a shileded locomotive.

Figure 5 is a photograph of the reactor-engine system on its way from the shop area to the nuclear operation area. Much of the apparatus that is shown in this photograph has been provided for developmental convenience and will not be used in an aircraft design. In particular, you will note that the engine is located at a distance of several feet from the shield. In an actual aircraft installation the shield will be much smaller and the engine will be coupled closely to the reactor-shield assembly. In addition, radiation levels outside the shield in the actual flight installation will be lower than in these early tests.

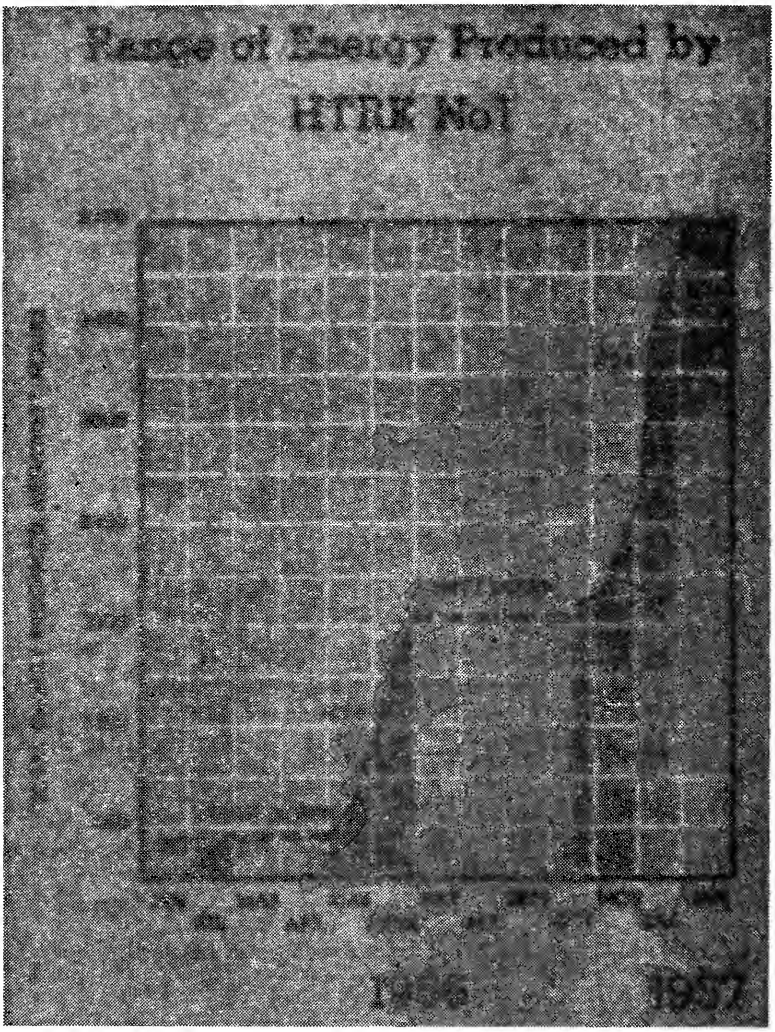


The shielded locomotive can be used as a traction unit to move powerplants between the shop area and the nuclear operation area; or, since it is heavily shielded, it can be used as a personnel transportation vehicle to approach the nuclear operation area when powerplants with thin shields and high external radiation levels are in operation. The assembly shown in the photograph is flexible; that is, we can test various nuclear reactors in the same shield and use the same turbojet engines. We refer to the assembly, therefore, as the core test facility. The various tests which we conducted to make use of this same assembly will be described. The first operation of an engine with nuclear power occurred in this test arrangement.

The area in which the test was performed is shown in figure 6. The main building is located below ground to use earth as shielding. The locomotive pushed the test assembly into the pad. The floor plan shows the area where the test assembly is coupled for test. All power leads, piping, and instrumentation and control leads are joined here. The other areas are for auxiliary equipment.



The engine tests started in January 1956, continued during the rest of the calendar year. (Figure 7 illustrates the operating history of heat transfer reactor experiment No. 1. Time is plotted along the horizontal axis, and the total number of nuclear megawatt-hours achieved is plotted along the vertical axis.) No control problem existed during starting. Operation was stable during the transition from chemical power to nuclear power. The reactor was always stable and responsive to both manual and automatic control during the entire test.



The first series of operational tests for heat transfer reactor experiment No. 1 was conducted during the 2-month period from December 1955 through February 1956. This test operation was successful; that is, the engines operated after startup without chemical assistance. There was an initial operating period of approximately 6 hours completely on nuclear power. During this operating period parts of three of the original fuel elements overheated; consequently, a nonhazardous amount of radioactivity was released into the air stream. After the initial 6 hours of operation the reactor was shut down and repairs were made. Operation was resumed and continued for over 80 additional hours. The corrective action taken was effective enough to restrict damage to a portion of one element. The radioactivity leakage was drastically reduced. Monitoring the area at all times by health physics personnel determined conclusively

that the fission products released during the 90 hours of test created no hazard. The total operating time at power was 90 hours. The reactor operation was entirely satisfactory (except for fission product evolution) at the time that it was shut down.

Upon completion of this operating phase the reactor was recharged with a complete set of new fuel elements. It was at this stage that the remote-handling ability of the "hot" shop (fig. 4) was proved. The shielded locomotive pulled the test power system from the initial engine test area to the turntable, was reversed, and pushed the system into the "hot" shop. This was accomplished completely by remote means. Once it was inside the "hot" shop, the massive doors were closed and no human hand touched anything directly until everything had been remotely disassembled and safely contained. Items such as the blower-hood assembly, which covers the top of the control rods, were taken apart remotely; all harness-to-jumper wiring was removed; all moderator valves had to be closed; and an impact tool had to be used to remove remotely the 98 bolts holding the reactor-plug assembly. When all outer piping was removed, the reactor was ready to be removed and inspected. Repairs were made, and the locomotive returned the power test system to the test pad.

The third series of heat transfer reactor experiment No. 1 tests was successfully conducted at predicted temperatures during the period from September 1956 through January 1957. The reactor was then operated for 100 hours without failure of any type. No detectable leakage of radioactive material into the airstream occurred during the entire 100-hour operating period.

At the completion of 100 hours of operation it was decided to increase the reactor temperature and continue operation in excess of the powerplant minimum requirements. The additional operating period lasted for a total of 40 hours under nuclear power. During this period some incipient damage of the fuel elements was detected. A small amount of radioactivity was observed in the airstream but the reactor operation was stable and responded readily to automatic and manual control. Again, health physics monitoring precluded the existence of a hazard.

The tests carried out on the heat transfer reactor experiment No. 1 were of great significance in meeting the objective of developing a useful aircraft nuclear propulsion system. For the first time all of the components of such a system were assembled and operated. Our tests proved the operability of the system and the predictability of performance. The tests also provided valuable information that was applied to design and operation of flight systems. Not the least important were the techniques and equipment developed to assemble, maintain, and inspect highly radioactive powerplant components by use of remotely operated equipment. These tests have served as an invaluable trail-blazer for other tests that have been completed or are now underway to meet our objective.

Address by Maj. Gen. Donald J. Keirn, Assistant Deputy Chief of Staff, Development for Nuclear Systems, Before the American Ordnance Association

Willard Hotel, Washington, D.C., November 20, 1958

November 20, 1958.

I'm sure each of you is aware of and appreciates the seriousness of any potential threat to our seacoast military installations and industrial and population centers posed by a large enemy submarine fleet. Imagine, in addition to this, a fleet of "enemy" high-speed aircraft continuously patrolling the airspace just outside our early warning net capable of air launching a devastating missile attack followed by high-speed penetration and attack against our hardened installations. Through a consideration of these capabilities combined with those possessed by the intercontinental range ballistic missile, the degree of the possible future threat of surprise attack immediately becomes apparent.

By recognizing the possible threats and pressures which may be brought to bear against us and our allies we can plan and program our future military forces in a manner which will continue to deter any enemy from a military attack upon us.

In face of the threat of a possible surprise attack, our deterrent posture can be maintained only by positively insuring the survival of an effective retaliatory force. At present, the Strategic Air Command bomber force is operating under a ground alert concept which will enable us to react within 15 minutes of the initial warning with a significant portion of the fleet. In the future, our planning will include the addition of hardened ballistic missile launching bases, and employment of a portion of our manned Strategic Air Command fleet on airborne alert if necessary.

An ideal airborne alert manned aircraft system must carry a large payload, and remain on nomadic patrol for extended periods of time in various areas of the world. It must maintain continuous communication with appropriate headquarters and be capable of instanteneous reaction with air-launched missiles. When required, the system should be capable of following up the missile-launching phase with a low-level, high-speed penetration of the enemy's heartland in order to seek out and destroy hardened targets or targets whose locations are not sufficiently well known to permit attack by long-range missiles. The combination of these features can best be achieved through the application of nuclear propulsion. And this leads me to the subject of my talk—the manned aircraft portion of the aircraft nuclear propulsion program, its history, its status, and my thoughts concerning its future.

After 13 years, the ANP research and development effort supported jointly by the Air Force and the Atomic Energy Commission has successfully passed many important technical milestones. We have operated turbojet engines in parallel from a common heat source. We have ground tested a turbojet engine on nuclear heat from a reactor. We have completed 47 flights of a one-megawatt reactor in a nuclear test airplane outfitted with a complete crew shield. This reactor was, of course, not used for propulsion. We have accumulated thousands of hours of irradiation testing of aircraft materials, components, and subsystems. We have made great progress in reactor design and development and in reactor and aircraft shield design and development; and we have experimentally verified many of our analytical techniques and materials parameters. These achievements are indicative of the broad development base which has been built by the Air Force-Atomic Energy Commission-industry team.

In arriving at our present position we have been over a long and tortuous road. Our problems have been similar to those found in any development program—attempting to achieve and maintain proper balance between military requirements on one hand and technical risk and cost on the other; trying to establish development objectives consistent with operational requirements and yet compatible with the technical risk and cost involved. For instance, a program to flight test a nuclear propulsion system in a modified B-36 airplane was canceled in early 1953 because the military potential of the airplane powerplant system was extremely limited and the cost was not considered justifiable on the benefits of technical development alone. Again in late 1956, work on a supersonic bomber for weapon system 125A was reoriented because the technical risk of success was considered too severe to justify the high cost.

During this period of time, our program has come under nearly continuous review by various scientific groups or committees by request of the Air Force, the Atomic Energy Commission, the Department of Defense, and other governmental agencies. Much of the advice by these groups has been the basis for the formulation of policy and the prosecution of the ANP program. The level of effort has, in general, been consistent with their recommendations. There have been, of course, divergent opinions expressed by various committee members; however, even these diverse views have served to assist project management in directing special emphasis in very specific areas. There also have been instances of advice, which, while sincere, could have had broad impact on the program had we not been able subsequently to show that the advice was based on insufficient factual considerations.

Let us illustrate. Three or 4 years ago a group of eminent scientists concluded that chemically powered aircraft will always be able to fly higher and faster than nuclear powered aircraft. The conclusion was based on the following simple technical fact. By assuming similar structural and container materials in a propulsion device, it was reasoned that higher temperatures could be

achieved in the propulsive media by burning chemical fuel in the media rather than by heating the media through the container walls, the wall temperature in each case being essentially the same. Subsequently, the Air Force was able to show that a nuclear powered system possessing speed and altitude capability comparable to chemical powered counterparts could be achieved by augmenting the thrust from the basic nuclear powerplant through chemical afterburning during these periods when such performance would be required.

I do not wish these comments to be taken in a sense derogative to our many scientific advisers, but rather as a caution with regard to forming opinions or reaching conclusions on the basis of single technical facts taken out of context, so to speak, with all of the related facts which may have a profound bearing on the matter.

Let me illustrate this point in another area which has generated divergent viewpoints. In our efforts to develop useful nuclear powerplants, we are faced with a requirement to keep the weight to thrust ratio as low as possible. One way that lower weight to thrust ratios may be obtained is by increasing the thrust through higher propulsive air temperatures. This, of course, can be achieved through the development of higher performance materials, and extensive heat must be generated within the solid matrix of the reactor, the requirement for better high-temperature materials goes beyond that in most other fields of development. This fact has been the underlying reason for much of the pessimism which has pervaded the comments of some of our foremost scientific counselors. Improvements in thrust can also be achieved, however, through adroit engineering design which takes maximum advantage of the available materials technology. However, it takes a healthy concurrent hardware testing program to adequately exploit this means of performance improvement. This fact does not seem to be fully appreciated by some scientists who continually advise less effort on hardware development pending further achievements in improved materials. We have accomplished significant increases in system efficiencies and performance using the same basic materials by expert design techniques and good engineering practice, and there is much more than can be done in this direction.

There is one other important area worth mentioning in which diverse opinions have created problems in program management. This is the matter of the potential radiation hazard associated with the crash of a nuclear powered aircraft. My attention has recently been drawn to an article on this subject. In recognizing the hazards of nuclear powered flight, the author describes the situation in wholly unreasonable terms. He was obviously not familiar with the intensive study that has been made of these problems in the ANP program. I can assure you that the Air Force and the Atomic Energy Commission are extremely sensitive to their responsibility for insuring the safety of the public in all of our test and tactical operations. We are conducting an extensive experimental program which will culminate in full-scale tests specifically designed to identify all conditions which could result in possible injury to people or damage to property. As a result of this effort, the Air Force will be able to formulate definitive test and operational techniques and procedures that will adequately protect the public interests. Articles like the one I have just mentioned completely obscure the true status.

But let me return now to the present status of the manned aircraft ANP program. I discussed at the beginning the general requirement for an airborne alert, mobile missile launching manned aircraft system. Such a system may be similar in weight and size to the B–52 and be capable of carrying a heavy payload on extended endurance missions. Because of its endurance, varying armament load, and high speed capability at minimum to median altitudes, its operational versatility would be outstanding. I have already mentioned some of its deterrent qualities with respect to general war situations. But perhaps even more important is its inherent operational flexibility for meeting various limited war and peacetime situations.

We are now on the threshold of success in the various technological areas, and will soon be ready to embark on an experimental flight development phase looking toward a prototype aircraft as the next logical step in the program. The proposed developmental approach is completely compatible with current technology. It provides for an orderly and sequential development program to achieve our objective of a militarily useful aircraft on a minimum risk, time, and cost basis by emphasizing safety, integrated powerplant and shield development, and equipment-proof testing. It will not require major commitment of funds until powerplant reliability is established, ground handling and main-

tenance techniques developed, and a reasonable amount of nuclear flight test time accomplished. Such a procedure is basically a "fly before buy" approach.

Recently, strong interest in a nuclear turboprop configuration has developed for applications for transporting heavy payloads at speeds somewhat lower than those for which the airborne alert system would be designed. Although the turboprop performance spectrum and installation complexity is not so favorable as the turbojet for satisfying the Air Force's high-priority strategic mission requirement, it does have significant capability in logistic, and other similar areas. The Air Force and the Atomic Energy Commission are cooperating with the Navy in conducting application studies in an effort to establish the most utilitarian propulsion configuration for such requirements. We feel that the necessary variations will logically come along as outgrowths of the basic Air Force turbojet program currently being pursued.

From what I have said, I think you have an appreciation of the impact that the current state of technology in nuclear propulsion will have on military capability and operations. We will essentially be able to add another dimension to our manned Strategic Air Command fleet—extreme range and/or endurance with large constant payloads. Similar advantages will accrue in other mission areas where it can be demonstrated to be practicable and economical.

I stated earlier that I would say something about where I think the future will take us. It is difficult to forecast the future trends in nuclear propulsion because the development problems are stringent and the development program is expensive and tied entirely to military needs. The propulsion systems we have under development today are but first steps. The problems of operating reactors at the required power density can be solved through the development of materials which are now known to us, and through improved design techniques which are evolving daily.

The shielding problem is not a bar to useful nuclear-powered flight where a requirement for long unrefueled flight exists. Capital investment will be high initially, but these should be counterbalanced by higher aircraft utilization rates. While one is tempted to put a timetable on the introduction of nuclear-powered aircraft to commercial use, I would hesitate to use previous history as a yardstick. Nevertheless, I expect one day to read the headlines where the first nuclear powered supersonic transport is introduced into commercial service between New York and the Orient.

Appendix D

Articles and Letters

[Reprinted from U.S. News & World Report, Dec. 12, 1958, an independent weekly news magazine published at Washington. Copyright 1958, U.S. News Publishing Corp.]

The Truth About a U.S. Atomic Plane

INTERVIEW WITH MAJOR GENERAL KEIRN, CHIEF OF NUCLEAR PLANE PROJECT

When you look into the sudden furor over nuclear-powered airplanes—

Where does the United States stand? Is Soviet Russia off to a long lead, as reported?

From a military standpoint, what difference does it make? How does an atomic-powered plane stack up as a weapon of the future?

Latest developments in a little-known phase of the space age are revealed in this exclusive interview with the Air Force general in charge of the U.S. atomic plane project.

Maj. Gen. Donald J. Keirn became a flier in 1930, an atomic soldier in 1946, and has been in charge of the A-plane from the outset.

At Las Vegas, Nev.:

Q. General Keirn, do you really believe reports that the Russians have an operative nuclear-powered airplane? There seems to be some doubt about it.

A. I can't say that I either believe or disbelieve. I have said in the past that it is conceivable they might have one.

Q. Does this country now possess atomic reactors that could be used to power an airplane?

A. No. Our reactor program has been a step-by-step development program, so there is not a qualified nuclear propulsion system to put in an airplane.

Q. Have reactors actually been flown in a U.S. plane for test purposes?

A. Yes; this is correct. They did not propel the airplane. We had such a reactor. We flew it in a B-36 for, as I recall, about 47 flights in which the reactor was operated for nuclear-effects reasons rather than propulsion.

Q. Under pressure to fly a nuclear-powered airplane as soon as possible, how soon do you think we might put one into the air in an existing airframe like the B-36 or B-52, and actually propel that airplane?

A. I would not want to put a timetable on it because our program is not directed in this manner. Consequently, if it were redirected in this manner, we would have to revise it and we would have to build such a propulsion system, and I don't know just how long it would take to do it.

Q. As of now, this is not a crash project in any way?

A. It is not a crash project.

Q. Would you say from what we know of the nuclear capability of Russia that she would beat us into the air with a nuclear airplane, even if the present reports are not true?

A. I believe if the Soviets concentrated on the job they might be able to beat us into the air. I don't know how effective or how valuable as a military aircraft it might be. But I think if they really made an effort just to get something flying they could possibly get one into the air before we do, because this is not our goal.

Q. What are the advantages of a nuclear airplane over a conventional jet?

A. Range and endurance. It gives you complete independence of required refueling, of required stops for fueling, and of required restrictions on choice of flight routes by reason of fuel exhaustion in the chemical airplane.

The nuclear airplane gives you essentially unlimited range. It is limited only by the requirements for the endurance of the crew. Of course, this implies that, for the longer ranges or longer endurances, a nuclear airplane can carry a greater payload than can the chemical airplane.

Q. Could the first nuclear airplane fly as fast—2,000 miles per hour—or as high—70,000 feet—as the B-70 chemical bomber?

A. We do not expect the first nuclear airplane to match the speed and altitude of the B-70.

Q. Would it be feasible to have more than one crew in such an airplane for longer flights, since crews are the limiting factor?

A. We would expect to have rest stations to achieve this in a partial sense. It would not be impossible to have complete rotation of crews, but this again ties in to the military requirement, and we have not seen this as a requirement.

Q. Is there unusual danger involved in nuclear-powered aircraft?

A. Yes, but I would prefer to say there are certain peculiar dangers rather than "unusual" dangers. They are related to the possibility of the release of fission particles from the reactor in case of a crash.

Q. That danger is greater than the crash of an airplane with a nuclear weapon which is not yet detonated?

A. Yes, if the crash resulted in the release of radioactivity. The question is a very complex one—it is one we are studying very extensively. I think the danger has been overstressed but, because it does exist, we plan to apply very stringent flight rules to nuclear-powered aircraft, rules which are a little bit different than for chemical aircraft.

We must have flight, airway and altitudes that all chemical aircraft must comply with. We will have to have compliance with certain airway restrictions, including airways, corridors and that sort of thing, not too far different from the rules we apply at present. If we can apply those rules, then there is no more danger to the public from a nuclear-powered aircraft than from a chemically powered aircraft.

The big problem is: Does someone stray from these corridors? Experience with the Strategic Air Command is that they can maintain strict discipline among the responsible crews; I would expect responsible crews to be flying nuclear-powered aircraft.

Q. What is the main problem now in developing such an airplane?

A. The main problems are associated not only with the shielding but with the reactor material from a nuclear and a temperature standpoint. We will always carry shields, maybe around the reactor, maybe around the crew, maybe around both.

There is no magic that will avoid the need for a shield that we are aware of. Mass is the only thing that stops nuclear radiation. We know of no phenomena other than mass of material that does so—so we will have to have shields.

The reactor materials are the thing that is giving us the greatest problem. That is the place where we are spending the major portion of our effort. Both of these problems are important and both of them are difficult. I believe both of these problems can be solved by hard, consistent work.

I would also like to emphasize that achieving a militarily useful aircraft requires much more sophistication in all technical areas than merely flying an aircraft on nuclear power as a stunt. This is the facet of the problem that is generally overlooked and with which the Air Force is currently grappling. It is our announced intention that a military vehicle is our objective. Even before construction of the first aircraft there are many problems which must be solved. We are currently investigating these in the most logical and practicable way we know how.

Q. With the increased capability of aircraft and the weapons they carry, fewer airplanes are needed. How many nuclear-powered aircraft might suffice for defense purposes?

A. I think your promise of fewer aircraft being required as weapons become more effective is true, but, nevertheless, we have plans of operations which call for a number of aircraft to fulfill certain planned missions. I couldn't give you this number. I don't know the number. It is a problem that the planners are concerned with.

Q. How much money has been invested in the nuclear-aircraft program to date?

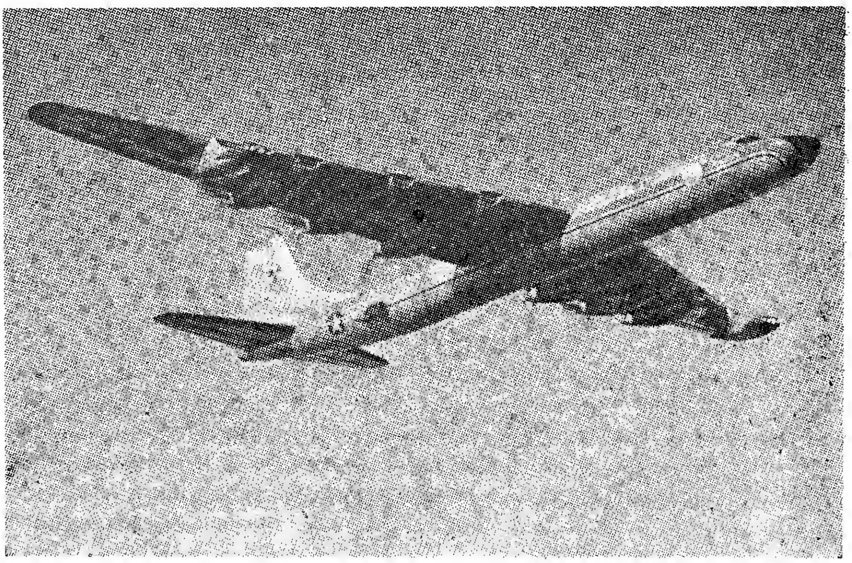
A. I believe the total funds between the Air Force and the Atomic Energy Commission are in the order of $600 to $700 million.

Q. How much more may be needed before the first airplane will fly?

A. This is a question which I cannot answer.

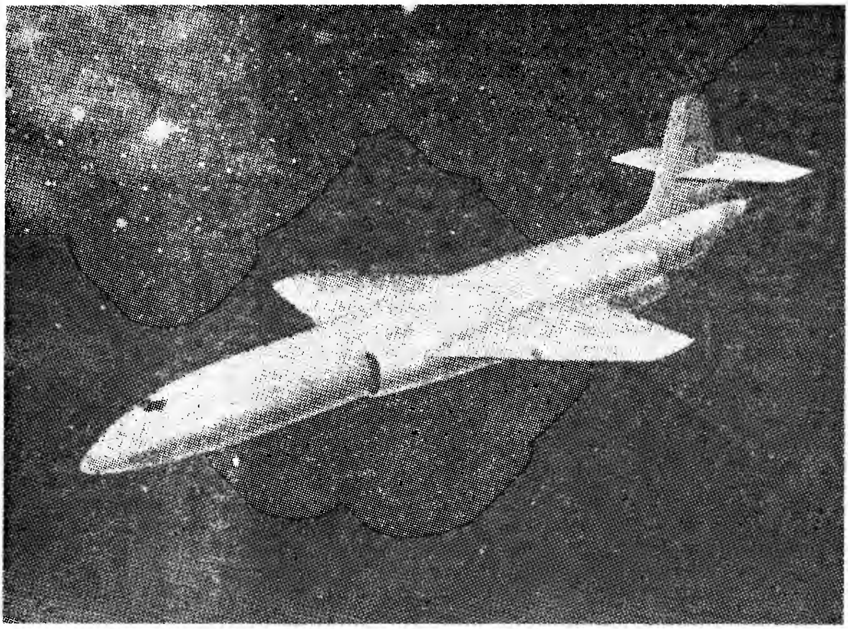
Q. Both we, with a rocket called the "Kiwi," and the Russians are reported to be near the point of testing a nuclear-powered rocket. How would its use and capabilities differ from present rockets?

A. Well, you understand that our program involves the development of a nuclear propulsion system for rockets. A nuclear-powered rocket will give us, we believe, a substantial increase in specific impulse. This means a substantially higher end velocity for a given propellant to total missile weight. This, of course, means that you can either lift a higher payload or you can achieve a higher velocity with a given payload.



—General Dynamics Corp.

Nuclear-Test Plane, a modified B–36 bomber, carried an atomic reactor aloft about 47 times for a series of experiments on radiation effects. The reactor did not power the plane and was turned on only when above unpopulated areas.



—Drawing by Lockheed Aircraft, from Wide World

The atomic plane might look like this. "The nuclear airplane," says General Keirn, "gives you unlimited range. It is limited only by the endurance of the crew." It will be able to carry "a greater payload than the chemical airplane."

Q. Such a rocket could be used both for defense and for space purposes?

A. It could be.

Q. Do you think the Soviet Union might be ahead of us in the development of such a rocket as they may be with the nuclear-powered airplane?

A. I hesitate to make any comments. We don't know very much about the Soviet's progress. They have a capability in this direction.

Q. Could such a nuclear rocket be monitored by stations we have surrounding the U.S.S.R.?

A. There is nothing peculiar to the nuclear aspects of it that would make it very much different from the chemical rocket, from a detection standpoint.

Q. Would the nuclear-powered missile be what is called "the ultimate weapon"? Is there such a thing?

A. I doubt that there is such a thing as an ultimate weapon. I believe that nuclear-propelled devices will come to be as important to our Nation's defensive posture in the time to come as are the nuclear munitions.

[From Aviation Week, Mar. 2, 1959]

THE CASE FOR NUCLEAR-POWERED AIRCRAFT

Public hearings on the nuclear-powered-aircraft program will begin soon on Capitol Hill thanks to the persistent proddings of Senator Clinton Anderson and Representative Melvin Price of the Joint Congressional Committee on Atomic Energy. This will be the first opportunity for the American public to get any reasonably clear picture of the status of our military nuclear-powered-aircraft progress and the real reasons why this progress has reached a point of virtual stagnation.

Until now, this program, with some genuine cause, has been heavily shrouded in secrecy. Only its opponents have been able to make public statements supporting their secret decisions to retard or eliminate its financial support. We

are all familiar with the "shitepoke" jibe of former Defense Secretary Charles Wilson, when he tried to wipe out the entire program in 1953, and the more recent and technically indefensible statement of President Eisenhower that a nuclear-powered aircraft, even if successful, "could only fly a few hundred feet off the ground" (Aviation Week, Dec. 15, p. 27). And, of course, the monotonous chant of Deputy Defense Secretary Donald Quarles with the leitmotif of technical timidity and false economy is a key roadblock in any attempt to organize and sustain any type of fruithful program in this area. Mr. Quarles' consistent record of opposing any promising new technical development program proposed in the Pentagon during the past 4 years, including the initial USAF space exploration efforts, the radar network to monitor Soviet missile tests, the WS–117L reconnaissance satellite and efforts on basic research hardly lend credulity to his testimony against the nuclear-powered-aircraft program.

We firmly believe, along with congressional and USAF, Navy and industry experts who have testified on the program that there is a vital need for an accelerated development program aimed at producing militarily useful atomic powered aircraft. Within the limits of this space we will try to summarize the case for this type of program.

First, there is a definite military requirement for nuclear-powered aircraft.

For the Navy, a large nuclear-powered aircraft with subsonic cruise speeds would make an ideal antisubmarine warfare weapon. Equipped with new and far-ranging detection devices now under development, a relatively small fleet of these aircraft could effectively comb critical expanses of ocean rapidly and effectively to locate enemy submarines and keep them under constant surveillance, even those using nuclear power. For the 40-knot speed of a nuclear-powered submarine would avail little against the 350-knot cruise speed of a nuclear-powered ASW plane. The Navy believes it can best utilize an airborne nuclear reactor to drive turboprop engines with a closed cycle type of operation. For only a few million dollars it could take the first vital step toward developing this aircraft using the *British Princess* flying boat hulls now in mothballs at Cowes.

For the Air Force, a nuclear-powered aircraft would serve several useful purposes. It would provide a vital new element of flexibility and dispersal to our strategic deterrent capability that would be militarily more effective and economically more feasible than current airborne alert plans with chemically fueled bombers.

A relatively small fleet of nuclear-powered bombers could remain on airborne alert continuously for periods of up to 30 days. They would require relatively short periods on the ground for maintenance and crew changes between missions. The entire fleet could be operated from a very few isolated island bases in the Atlantic and Pacific. These aircraft could carry heavy loads of long-range detection gear to provide a mobile flexible warning coverage beyond the capability of the fixed, immobile stations of the DEW Line and BMEWS that are so vulnerable to enemy ballistic missile attack.

The nuclear aircraft could also carry a sizable load of solid-fueled air launched 1,500-mile ballistic missiles that would provide an important, dispersed and quickly available element of our strategic deterrent.

In addition, the unlimited range of the nuclear-powered aircraft makes it ideally suited for low-level penetration to enemy targets under or around radar and missile defense systems. The high-altitude nuclear explosions from Johnson Island during the Hardtack operations in 1958 marked the turning point for both offensive and defensive aerial delivery systems. The nuclear effects at high altitude are so widespread and devastating from heat and radiation that neither presently known aircraft structures nor nuclear offensive armament can remain useful when subject to its effect even at long range.

It is this capability for long-range, devious, low-level penetration, most probably through holes in an enemy's defense blasted by its own air launched missiles, that gives the nuclear powered bomber a capability utterly impossible for chemically powered aircraft even with aerial refueling.

The nuclear-powered aircraft also fits into the military picture as a long-range, heavy-cargo logistics support aircraft that could operate without refueling over intercontinental roundtrip ranges.

Second, the development of useful nuclear-powered aircraft is technically feasible, and this feasibility has been demonstrated in an experimental environment.

The 13-year development program, starved for funds in its best years and almost choked lifeless by several economy-dictated decisions, has laid the basis for technical exploitation into workable hardware. If any doubts remain—and there are none among the technical personnel actually working on these projects—they will soon be dispelled by the public appearance of a Soviet nuclear-powered aircraft whose existence was exclusively reported in Aviation Week, December 1 (p. 27). The public appearance of a nuclear aircraft during 1959 also was unequivocally promised by the official Soviet radio New Year's Day scientific broadcast. There are many difficult engineering problems, particularly in high temperatures metallurgy, between experimental feasibility demonstration of airborne nuclear power and production of useful operational hardware. But the latter goal will never be achieved unless we take the first steps with the determination to progress through increasingly better systems until the desired efficiency and reliability are achieved.

Third, radiological safety will permit operation of nuclear-powered aircraft for military purposes, including exposure of aircraft crews and ground maintenance personnel and the civilian population at large.

Many horror stories have grown to credulity in the atmosphere of unnecessary military secrecy that has surrounded the radiological safety aspects of nuclear-powered aircraft both in the air and on the ground. There is no good reason why the results of military and industry studies and tests in this area should remain secret any longer, and we hope Representative Price's group will pry it loose in the public interest.

Our nuclear-powered-aircraft program has suffered severely during the past five years from financial starvation and constant shifts in goals and pace by people who have had only the briefest and most vague contact with, or understanding of, the genuine problems involved in this undertaking. At this late date in the history of our technological weapons development race with the Soviet Union, it is imperative that we organize a technically sound and militarily useful nuclear-powered-aircraft program. Then, we must sustain it through its inevitable development problems and occasional experimental failures and finally employ its eventual products usefully in the military pattern of the future that is essential to maintain our position of leadership for the free world.

ROBERT HOTZ.

[Reprinted from Aviation Week, Aug. 3, 1959]

SPOTLIGHT ON NUCLEAR PLANE PROGRAM

(By Robert Hotz)

The open congressional hearings on the military nuclear-power-aircraft programs sponsored by the Air Force and Navy have shed considerable light on the past performance, current situation, and future prospects of this security-shrouded, budget-slashed program. The American people owe considerable thanks to the Joint Congressional Committee on Atomic Energy and the sparkplugs for these specific hearings, Senator Clinton Anderson, Democrat, of New Mexico, and Representative Melvin Price, Democrat, of Illinois, for their persistence in demanding a public accounting on this program.

The most important fact to emerge from these hearings is that, despite other indications to the contrary, the nuclear-powered-aircraft program will be pushed at a moderately accelerated rate in the future and that considerable thought will be given to establishing a more effective technical direction of an overall program pushing both the General Electric Co. direct air cycle approach and the Pratt & Whitney Aircraft indirect cycle approach where major technical breakthroughs have resulted recently.

It is evident from testimony of Dr. Herbert York, Defense Department Director of Engineering and Research, that considerably more emphasis will be placed on reactor and materials development and less emphasis on putting a flying testbed into the air to gain flight experience with nuclear powerplants.

Certainly there can be no argument with the thesis that major emphasis must be given to research on improved airborne reactors and the materials required for them. However, there is considerable difference of opinion on the abandonment of the construction of prototype nuclear-power aircraft to gain flight experience with a complete system of this type. Dr. York and his scientific advisers argue that this would hardly be a useful exercise in advancing the

state of the art. It is apparent from their testimony that this technical viewpoint also is strongly tinged by the current budget problems of the Defense Department, and it is often difficult to measure where the technical considerations end and the budget influence begins.

Maj. Gen. Donald Keirn, who has directed the USAF portion of the ANP program and whose experience in developing radically new types of power goes back to the first turbojet engines, takes the opposite view. He believes the experience gained from flying nuclear-powered prototype aircraft with powerplants that it is technically possible to develop now, would provide valuable experience necessary to the ultimate development of a useful weapon system. General Keirn must find many of the arguments advanced against the nuclear prototypes very familiar as they are the same arguments advanced by many apparently competent technical "experts" in the thirties and early forties against the application of gas turbine power to aircraft. People with sufficiently long technical memories will recall that even such ordinarily sage advisers as the National Advisory Committee for Aeronautics dismissed jet propulsion on the ground that it would hardly be useful unless aircraft speeds were over 500 m.p.h. And such speeds were obviously not in sight. But only a few years after that judgment was rendered the German ME 240 twin jet was fighting at speeds in excess of 500 m.p.h.

General Keirn must recall the difficulties involved in getting USAF acceptance of jet propulsion in the early forties when only the unswerving determination of the late Gen. Henry H. Arnold, overruling his technically timid subordinates, pushed the project through to successful completion with the help of General Keirn and others not so technically conservative.

It also is appropriate to recall in this controversy the case of the XB-15 and XB-19 experimental heavy bombers built by Boeing and Douglas respectively. Only one of each was ever built, and they were "too slow" to be useful for combat. Yet the experience gained by building and flying these experimental giants laid the technical foundation for the development of the combat-capable heavy bomber lineage of B-17, B-24, B-29, B-32, and the four-engine transport fleets that made U.S. manufacturers supreme in this field during the postwar decade.

It is easy for technical "experts" lacking the background in aircraft development problems to dismiss too lightly the need for experimental flight experience as a sound foundation for ultimate military developments.

There was considerable testimony submitted by such technically competent witnesses as Gen. Thomas White, Dr. Herbert York and his staff, Vice Adm. J. T. Hayward, General Keirn, Roy Shoults of General Electric, and John McCone, Chairman of the Atomic Energy Commission, who has had considerable experience both in aviation and nuclear developments. The conflicting viewpoints expressed by these gentlemen should be carefully considered in formulating a new and more solidly supported nuclear-aircraft propulsion program.

In contrast, the testimony of some newcomers to the Pentagon scene should be heavily discounted as a mere parroting of the Budget Bureau party line.

It has been the sad history of the nuclear-powered aircraft program that it has been the technical people who have been closest to the program, both in the military and industry, who have had the strongest faith in its ultimate success, and it has been the politically appointed Defense Department officials and the bookkeepers of the Budget Bureau who have been most pessimistic and have tromped hardest on the brakes to slow its progress.

The congressional hearings have done much to clear the security-shrouded air surrounding this vital program. We hope that USAF, the Navy, and Atomic Energy Commission will join with General Electric, Pratt & Whitney Aircraft, and airframe constructors to formulate a technically vigorous program to drive ahead with maximum speed to produce militarily useful results.

Why an A-Plane Crash Program Won't Work

(By Fred Hamlin)

[Armed Forces Management, January 1959]

All that this country's nuclear airplane program needs is more active backing and a powerplant.

What is needed for the engine: between 3 and 4 years, with a spending level of about $250 million a year. This, according to top Air Force sources, will build the engines and airframes to put two prototype aircraft into the air under

nuclear power. Past spending on the A-plane program has averaged roughly $150 million yearly, with a total investment approaching $850 million.

The Russians—in spite of skeptically greeted reports to the contrary—will not have a nuclear plane in the air until about this time next year, but they will undoubtedly be the first to fly an A-plane.

The reason: It will be between 3 and 4 years until the United States has a nuclear engine that is ready to go. Although the Air Force has tested its nuclear turbojet on the ground, it has not yet begun to do anything in the way of flight testing. The one exception is a series of radiation shielding tests that have been run with an airborne reactor in a B-36.

By the time the nuclear engine is ready, the Air Force will have an airframe ready to go. General specifications for this plane have already been drawn up. What the Air Force wants: a Mach 9 aircraft, capable of cruising up to 5 days at altitudes to 40,000 feet. The A-plane will be powered by two turbojet engines, mounted close inboard and powered by a single nuclear reactor.

For this—or for any other flying nuclear plane—they will have to wait. There are no major problems to be solved. Says an informed Air Force source, "We have a damn good handle on all our problems. From here on in, it's just engineering and testing." Contract on the A-plane's airframe is still in the competition stage, with Lockheed and Convair as leading contenders. But there will be no atomic engine to put in the aircraft for the next couple of years.

While this plane will be only a prototype, Air Force has definite plans for using an A-plane, once they have it. Primarily, it will be used as "an atmospheric extension of the Polaris fleet ballistic missile system." The airborne missile platform would complement, rather than replace or detract from, the Navy system. Air Force also sees a definite use for the plane in limited war situations. It could be used to hover over battle areas, working with U.S. ground forces, firing low yield atomic rockets or laydown atomic weapons. Finally, such a plane could be used to plug the gaps in the ballistic missile early warning system (BMEWS).

Air Force maintains, contrary to the Navy, that there is no need for a test bed phase of development, in which the powerplant would be used to propel and existing airframe (most likely prospect, if there were such plans, would be the British flying boat, *Princess*).

While Navy's argument for a test bed is summed up by saying "you have to crawl before you can walk." Air Force points out that they have been "crawling" to the tune of $750 million on drawing boards and in component testing. Navy has not spent anywhere close to this much money (current figures: roughly $35 million). In some quarters, it is felt this is why Navy is pushing a test bed phase, reasoning that the Navy doesn't really know where they want to go with an A-plane.

Navy is currently backing a seabased turboprop version of the nuclear plane. Air Force points out that the main advantage of the nuclear aircraft is that of range and endurance. To fly this kind of mission will dictate reliability practically unheard of in the past. Because it must turn a propeller, the turboprop engine is that much more complex and unreliable. Air Force has had trouble with the jetprop engines it already has, and is more than happy to use the straight jet for the atom plane.

A major advantage of the nuclear aircraft is the variety of uses to which it can be put. Says a top Air Force source, "We just don't expect an obsolescence problem with the nuclear plane, once we have it. As our specifications stand, the plane is primarily a carrier type of aircraft. It will carry enough of a payload to insure a long, long life. If better reactor systems or materials are designed, they can be incorporated in our plane. If a better turbojet engine is built, it can be coupled with the reactor we have built into our plans."

While the Navy would compare the switchover to nuclear propulsion with the revolution to jets from reciprocating power, the Air Force discounts the idea. "A turbojet engine is a turbojet engine. What we are doing is about the same as the difference between flying a jet engine with JP–4 or JP–6 fuel."

Another argument for the Navy seaplane program is that of safety. It is no secret that there is considerable radiation hazard from the type of reactor that will be used in the A-plane. Navy claims that their test-bed program, using the British Princess, will offer the added safety of water operation, until more is known about handling nuclear power. Because water is an excellent natural radiation shield, and because the power system will be extremely heavy, any accidents will virtually take care of themselves.

Countering this, Air Force says it will maintain the most stringent safety rules. For example, if the plane is flown from an inland base, it will fly over land on chemical power, and will not turn on its reactor until it is over water. Also, Air Force is taking proximity of water into consideration in picking its A-plane bases. Obviously, the plane would only operate over areas of extremely sparse population.

As far as the Air Force is concerned, shielding, and resulting weight penalties, are no problem. They are a fact of life. Top sources say that there is absolutely no foreseeable relief from this problem. "There is no way but mass to kill radiation. An ordinary plane must take off with a much heavier fuel weight than when it lands. Of course, the A-plane won't. If we can save something on our takeoff weights, it could do much to counteract our shielding-weight problem."

Air Force stresses that they are not attempting, or even thinking about building a complete weapons system from scratch. What they are putting together is a prototype. It will be a less than immediately useful plane, but it will be one that is readily adaptable to military operations.

A major problem facing the U.S. nuclear aircraft development program would appear to be erratic backing. The Government—particularly the executive branch—has made a fairly steady practice of slowing up, and/or shooting down the whole idea.

This recalcitrant attitude is neatly stated in a quote from former Defense Secretary Charles Wilson. His remarks were made in 1953 in connection with a budgetary decision he had made which came uncomfortably close to stopping the A-plane program in its tracks. Said Wilson: "The atomic-powered aircraft reminds me of a shitepoke—a great big bird that flies over the marshes, you know, that doesn't have much body or speed to it, or anything, but can fly."

To say that there is no use for a nuclear-powered plane is to immediately discount the Air Force argument for a cruising missile platform—and to discount this is tantamount to admitting that the entire Polaris missile program has been a waste of time and money.

It is also to deny Navy's request for a long-range, high-endurance aircraft to be used in antisubmarine warfare and airborne early warning work. It also denies the use of this plane in a limited-war situation. In short, by so easily writing off the nuclear aircraft program, Secretary Wilson would appear not to know what plans had been made for such an aircraft.

After being shot down by Wilson, the program was saved by last-minute hustling on the part of the Joint Atomic Energy Committee. In 1956, the Air Force picked up the ball, and began to run. But technical difficulties obscured a completion date, and because of the program's general vagueness, A-plane funds began to dwindle.

In 1957, spending picked up again, and continued at a fairly even level until this year. A sharp blow was dealt this spring when President Eisenhower vetoed emergency A-plane funds, saying that there was "no urgency." The President would do well to heed a comment by J. Carlton Ward, Jr., president of the Vitro Corp. of America, and former head of the original A-plane program in 1946. His comment: "We could have had an atomic plane by 1952 if we had gone ahead with the program."

The President has maintained a fairly consistent approach to the problem, and one which seems to be dictated by the state of the art. His contention is that there is no point in rushing into the air with a "shitepoke" airplane. Because the country doesn't seem to be in a position to do this, the contention is hard to shake. What the President is saying is that as long as we have to wait for an engine, we might as well try to do the whole show at once. This is clearly underlined in his March 1958 letter to Representative Melvin Price, Democrat of Illinois:

"My conviction is that our need for the development of the high-priority military aircraft overrides the 'first nuclear flight' objective. Accordingly, I have decided that we should continue to go forward as rapidly as we effectively can with our development program, which at this stage places major emphasis on materials and reactor research, rather than to rush development of a first nuclear flight aircraft which would have little or no practical utility and would delay achievement of an effective military aircraft."

In a late December press conference, the President had this to say: "There is no usefulness that anyone could possibly see for such a plane [the nuclear test bed], and, therefore, our own research efforts have been developed toward

the production of an airplane that will have satisfactory performance characteristics either for some peaceful or military purpose, but we do not abandon the basic research on the powerplant * * * which is the basis of the whole thing. And we just merely say that there is no use of going into a field where the whole purpose would be to get a plane a few hundred feet off the ground."

It is not the fault of Congress that the United States is behind. Funds were voted, and then vetoed early this year that would have gone to A–plane development. By and large, Congress has shown interest and active support where this project is concerned. But Defense Secretary McElroy has said, in the face of Soviet success rumors, that "we do not contemplate any change in our program at this time." Perhaps a change isn't needed in the program itself. But the A–plane development program must be given much more active support than it has received in the past.

It has been suggested that what the program needs is another Rickover type, who will, plain and simple, ramrod it through. Because of the unique requirements that must be met, patience is probably closer to the point.

The truth of the matter would seem to be that the United States has lost the A–plane race by a margin even wider than was the case with sputnik. All of the fly-early plans are predicated on an engine; and from all indications, this country doesn't have an engine ready to go, and won't for the next 3 or 4 years. With this in mind, it makes no difference whether we fly a test bed or a prototype aircraft designed to mate with the nuclear engine—it is still going to be at least 3 years before we get a plane off the ground.

A U.S. A–plane, carrying nuclear-tipped missiles, used with the B–70, B–58, Minuteman, and Polaris systems, is going to form a retaliatory power that will virtually rule out a surprise attack against this country. The program is one of vital importance. It will do no good to put the A–plane program on a fly-first crash basis; but it will do even less good to fail to give it the money and support it deserves.

CINCINNATI, OHIO, *February 14, 1959.*

Subject: The aircraft nuclear propulsion program.

Hon. CLINTON P. ANDERSON,
U.S. Senate, Washington, D.C.

DEAR SENATOR ANDERSON: One month ago, on January 14, I sent the attached letter to the President concerning the national aircraft nuclear propulsion program. In this letter I stated that I did not plan further distribution until after an appropriate period of time had elapsed and would not further distribute this information should he instruct me that such an act would be contrary to the best interests of the United States.

One month has now elapsed. No further word has been received from the White House.

Due to your expressed interest and work in the area of the ANP program, coupled with your responsibilities as a member of the Joint Committee on Atomic Energy and the Senate Committee on Aeronautics and Space Sciences, I am here transmitting this information for your use as you see fit.

Speaking frankly, I have become convinced that if any corrective action can be taken, the impetus for same must now come from the legislative branch of the Government. All other avenues of approach to the decisionmaking problem appear to have been exhausted.

I join you in your conviction that the ANP program badly needs a definitely targeted date for nuclear flight, with programatic decisions and funding levels consistent with that target. Without same, there is no possible ANP program which can still meet the needs of this Nation.

Sincerely,

JOHN W. DARLEY, Jr.

NOTE.—Additional copies of this letter to the President are currently being transmitted to Representative Carl T. Durham, Representative William E. Hess, Representative Melvin Price, and Representative James E. Van Zandt.

CINCINNATI, OHIO, *January 14, 1959.*

Personal and urgent.

Subject: The aircraft nuclear propulsion program.

Hon. DWIGHT D. EISENHOWER,
The President of the United States,
The White House, Washington, D.C.

DEAR MR. PRESIDENT: I am an industrial manager engaged in the national aircraft nuclear propulsion program, having been connected with this activity for the past 7 years. I have sought neither counsel nor approval from my associates or superiors, however, for what I am about to say.

I am speaking as a conscientious voting citizen who is sorely troubled by the trend of events taking place in the world around me.

While the individual statements contained within this letter are not security classified, their overall content is certainly sensitive. Since you occupy the most powerful office in the world and are the only common authority over all of the agencies and departments who effectively administer the national ANP program, however, there are certain things which cannot be left unsaid.

I am trying to gain your confidence that what has been written here has been decided upon after very careful personal thought and after an evaluation of the pending risks versus the responsibilities involved. Opinions, of course, must be properly evaluated; please consider my specialized experience and the personal knowledge thus acquired when you evaluate mine.

On December 10, during your scheduled press conference, and in answer to a question on the subject of aircraft nuclear propulsion from Mr. Merriam Smith, you are reported to have replied as follows:

1. "There is no usefulness that anyone could possibly see from such a plane."
2. "There is no use of going into a field where the whole purpose would be to get a plane a few hundred feet off the ground."
3. "There is absolutely no intelligence to back up a report that Russia is flight-testing an atomic-powered airplane."

I recognize that your responses were based upon the best information available to you. I am only concerned as to the quality of that information and—speaking frankly—it is my opinion that you have been on the receiving end of some sloppy staff work which may be setting some sort of historical records in this direction.

Because I know full well that this letter has only a small chance of reaching you through a buffering staff wall unless some incentives are offered, I have simultaneously prepared copies of this letter for eventual distribution to the managing editors of selected magazines and newspapers. I do not plan to send these copies to these editors until after an appropriate period of time has elapsed and will not send same if you instruct me that such an act would be contrary to the best interest of the defense of the United States.

You may be wondering why I have delayed so long after your press conference of December 10 before sending you this letter. Speaking frankly, I have been caught on the horns of the dilemma as to whether or not I would be doing the ANP program more harm than good by responding to the situation in this way. The compelling reasons behind my choice were that:

1. The situation is urgent.
2. It does not show signs of straightening out through the normal channels.
3. The problems of understanding and motivation are so massive that it appears to me that they can only be overcome by a thorough airing.

The text which I have used, and which is attached to this cover letter, is quite lengthy; to assist you in its understanding, I will be following this outline:

I. Strategic considerations.
II. Soviet ANP capability.
III. The promise and status of the U.S.-ANP program.
IV. Criticisms of the U.S.-ANP program.
V. The national problems of administering the U.S.-ANP program.
VI. Recommendations for action.
VII. Concluding remarks.

It is my hope that by the time you have digested these remarks you may agree with my premise that you have not been receiving the best in information. Further, I hope that, through such an overall view of the ANP program, you will

join those of us who are moved by a compelling faith and conviction that the program is vital to the continued security of the United States.

At the least, I hope that I have provided another point of view.

Sincerely,

JOHN W. DARLEY, Jr.

I. STRATEGIC CONSIDERATIONS

Let me talk to your first point that "there is no usefulness * * * from such a plane," dealing in order with various elements of national strategy.

If I correctly understand our country's strategic concepts for survival, they are based upon:

(a) Posing a massive retaliatory threat such that a potential enemy cannot help but see that he will suffer considerably more damage than he will be able to inflict should he decide to start anything. In consideration of the amount of effort which is going into it, this seems to be our No. 1 strategy.

(b) Erecting sufficient air defense to warn of an incoming attack in sufficient time to permit the dispatching of our retaliatory force, to minimize civilian casualties, and to cause an enemy some loss in his attacking force; included in this element is passive civil defense through dispersal, evacuation, shelters, etc., on which little has been done to date.

(c) Deploying sufficient mobile ground and sea forces to quench local eruptions in so-called police force actions or "small wars."

NO PREVENTIVE WAR—WHAT THIS MEANS

I share with you the absolute conviction that the United States must never engage in a "preventive war"; this then rightly means that we have effectively granted an enemy any advantage accruing to the initiative. Any retaliatory threat posed by the United States will, therefore, only prevent a war as long as a potential enemy can only conclude that he will not be able to stop this retaliatory force from destroying those targets which he cannot afford to lose if he is going to eventually prevail in the disagreement.

I agree with you that there will be no "winning" of any future war—only the "prevailing" of one ideology over the other. It is my opinion that a disciplined and ruthless enemy will decide that the side which "prevails"—all other massive destruction forgotten—will be that side which has remaining an active strategic force after all the major strategic forces of the other side have either been spent or destroyed.

Our real war to end war, then, is the task of convincing of the other side that—

(a) he cannot save any portion of his active strategic force should he decide to embark on the path of armed conflict—regardless of how mobile and unpredictable in location that strategic force may become.

(b) he cannot destroy the strategic striking force of the United States, due to the fact that it is mobile and dispersed beyond his reach or beyond his ability to destroy before it retaliates against his forces.

THE CONCEPT OF MOBILITY—ITS MEANING TO US

I realize that the above looks like the application of a double standard to the two systems. The key to this effect is that for the United States and the Western allies "mobility" provides an even greater advantage than it does for the Soviet Union. This is because of the fact that—

1. We are already granting them the initiative; any additional advantage due to mobility is sugar coating to their main capability and mainly defensive against our retaliatory strike.

2. The world's area available for on-alert dispersal of our mobile force far exceeds that behind the Iron and/or Bamboo Curtain.

I will be dealing more with the meaning behind this concept in subsequent paragraphs.

THE RETALIATORY THREAT

Our No. 1 strategy—the retaliatory threat—including current plans for the implementation of same, involves the use of—

1. Intercontinental missiles;

2. Intermediate-range missiles—ground-, air-, and undersea-launched; and

3. Manned strategic chemically powered bomber aircraft.

WEAKNESS OF MISSILES

All of these missiles, since they can hit targets of known importance and location, are certainly vital weapons in the military inventory. They do, however, suffer on two counts—one of which is being worked on and the other of which is beyond their reach—

(*a*) In that all missiles have to possess sufficient protection against attack or a sufficiently quick response time to get off the ground after warning and before the enemy's weapons strike—they either have to be put on active standby underground or under the sea—or fueled by propellants which permit the necessary quick response on short notice (hopefully 15 minutes in the case of the ICBM's but shorter in the case of the IRBM's). I can see that both of these methods of improvements are being undertaken.

(*b*) In that missiles, however, are only able to hit targets of known importance and location, they absolutely fall short of being able to hit the highest priority targets; namely, those containing or contributing to the enemy's mobile strategic striking force—a force which can only be predicted in location by the most detailed intelligence information. It is my understanding that we do not have nor will we ever have this quality of intelligence coverage. Should the Russians come to possess operational quantities of air-orbiting nuclear-powered aircraft, the problem will become even worse than in our current situation—which is already difficult enough (I will deal more with this later).

CONTINUED NEED FOR MANNED AIRCRAFT

Because of this need to pose a threatened strike at these mobile and unpredictable "targets of opportunity," the role of the manned aircraft will continue to exist. The availability of human eyes and human minds in target areas—whether on weapons carriers or reconnaissance vehicles—is absolutely needed if these highest priority military targets are to be identified and subsequently destroyed. That this need will continue into the future is verified by the existence of the B–70 program.

WEAKNESSES OF CHEMICALLY POWERED AIRCRAFT

Chemically powered aircraft, however will suffer some definite drawbacks during future years due to the following:

(*a*) *Limitations in airborne time—risks taken.*—Because of the fact that airborne time—limited by chemical fuel capacity or by the programing or logistic complexities of inflight-refueling operations—is relatively short compared to ground turnaround maintenance time, only a fairly small proportion of a total chemically propelled bomber force can be in the air at any one time—or, for that matter, be gotten into the air within the period allowed by a 15-minute alert warning time. This means that, assuming that a potential enemy would logically concenrate on such ground-bound targets, only a fairly small proportion; namely, that airborne, would survive the initial, all-out blow.

I recognize that it is hoped that geographical base dispersal will save a larger proportion of the force which cannot get off the ground prior to the attack. My only reaction here is that, for the long-term future, the cost of an enemy's missile and launching sites zeroed-in on a larger number of dispersed bases will be appreciably less than the cost of these dispersed bases. For those who say that the potential enemy's ICBM's are not as accurate as required, I can only say that if this is true now, it won't be true for long.

(*b*) *Complicated fuel logistics—risks taken.*—Because of the fact that modern-day military strategic aircraft require extensive aerial inflight-refueling in order to reach their targets, the total operation becomes dependent upon a critically linked chain of events involving—

1. The availability of aerial tanker bases—both within the continental United States and overseas—all of which are subject to the same manner of obliteration and the need for discouragingly quick response times that

apply to the regular bomber force; as a matter of fact, this could be the major weak link in the chain.

2. A critically programed and externely complicated requirement for rendezvous meetings between the surviving bomber and tanker forces at the right time and at the right place and with the right amount of fuel available.

(c) *Vulnerability of chemically powered aircraft at high altitudes.*—Due to the technical characteristics of air-breathing jet powerplants, chemically powered strategic aircraft—even if suitably refueled near the enemy's perimeter—can only reach the required target areas by flying at high altitudes. If I interpret the recent test results on high-altitude nuclear bursts correctly, the survival of a manned aircraft at high altitudes—almost regardless of the speed at which it is traveling, will become increasingly less probable with the passage of time. If during the target-zone penetration portion of their mission, chemically powered aircraft are forced to low altitudes, their range becomes so limited as to reach only a small proportion of the required target coverage.

This then is a technical fact. There is no known way by which any current or proposed chemically propelled strategic aircraft can reach anything more than a very small proportion of required target areas if it is required to approach same at low altitudes. This same limitation does not apply to nuclearly powered aircraft.

THE PROMISE OF NUCLEAR-POWERED AIRCRAFT

There then—due to an imposing combination of the above—is one primary regime of usefulness for the nuclearly powered aircraft—namely, in the area of retaliatory threat, strategic reconnaissance and bombardment.

1. *Nuclear-aircraft—extended airborne alert*

Because of their inherently large "fuel" capacity, nuclear aircraft will have much extended airborne times, i.e., the amount of time they spend in the air will grow to equal or perhaps even exceed the amount of time they spend in maintenance turnaround on the ground. This means that a much, much higher percentage of the total number of aircraft will be airborne at all times—airborne and armed at variable and unpredictable locations throughout the world from which they pose a maximum retaliatory threat without range limitations.

In effect, this airborne alert capability raises the percentage of the total force which is saved from the initial enemy blow in order for it to be able to go on and do its job. A potential enemy, recognizing this capability, is thus faced with the realization that he will not be able to eliminate that which will eventually destroy his mobile strategic force. I would call this an improved retaliatory threat.

2. *Nuclear aircraft—independence from complicated logistics and foreign bases*

Already airborne, the nuclear aircraft can do its job independent of any need for aerial inflight refueling or foreign-based aerial tanker fleets. It is my opinion that our relations with our allies are or will be increasingly strained by the existence of these tanker fleets based overseas (and which constitute important military targets) in much of the same way that there was definite foreign reaction against the basing of IRBM's in England or Italy. I am not proposing isolationism—only trying to identify a trend in the climate of world opinion.

3. *Nuclear aircraft—versatility in application*

Once airborne, that portion of the nuclear-aircraft force on retaliatory patrol duty is independent of any other logistic need—and only requires a signal that the United States has been attacked and that it should proceed on its assigned retaliation mission. Due to the inherently large weapons-carrying capacity of nuclear aircraft, its armament can include a number of air-launched air-to-ground missiles and regular "laydown" weapons which far exceed the weapons-carrying capability of their chemically powered counterparts. This means that fewer aircraft can do the job.

Due to this enlarged load-carrying capability—coupled with high endurance—the nuclear strategic aircraft possesses a tremendously improved versatility in usage which embraces—

(*a*) Airborne retaliatory patrol—safe from initial attack.
(*b*) Missile-launching from outside the enemy's defense periphery.
(*c*) Reconnaissance and warning near the enemy's periphery.

(*d*) Omnidirectional low-altitude penetration under the enemy's radar warning net for reconnaissance and location of the enemy's mobile strategic forces.

(*e*) Low-altitude penetration—followed by either missile-launching and/or conventional bomb laydown—or by a combination of both.

The significance of the low-altitude approach is treated in the following paragraph.

4. Nuclear aircraft—potency of alternate low-altitude attack

Contrary to the range limitation of chemically powered aircraft at low altitudes (where survival will become increasingly more probable than penetration at high altitudes), a nuclear aircraft could actually come down from its cruise altitude and penetrate the enemy's early-warning perimeter from an infinite choice of directions and at extremely low altitudes—holding this low altitude on its way to its assigned target area. If you want to get a reading as to the enormous potential potency of this kind of attack, I would suggest that an answer can be acquired by postulating that an enemy had such a method of delivery. The answer may surprise you.

For those who would say that it is easy for a potential enemy to protect itself against such a manned retaliatory force, I would suggest that for a country with the land mass and extended perimeter of Russia, they are welcome to try. The Soviet Union could very easily bankrupt itself in just erecting a low-altitude warning net—not to mention the number of active defensive missiles and aircraft which would have to be employed.

5. Nuclear aircraft—fewer aircraft, fewer bases

Let us talk next as to the number of bases from which nuclear aircraft would need to be deployed. Because of the fact that a higher percentage are airborne at all times, because each aircraft has appreciably more weapons capacity, and because lower comparative attrition can be increasingly expected due to the omnidirectional low-altitude attack—a much fewer number of manned strategic aircraft would be needed. This translates into a fewer number of costly bases.

My best estimate is that from two to three nuclear-aircraft bases—appropriately located on Atlantic and Pacific islands to take an enemy's major attack away from the continental United States—would do the peacetime job. It is to be assumed that all of these bases would be lost in an initial attack—but an attractive percentage of their based force would have regularly been airborne and would constitute a manned strategic force to fight the war.

The next question here is that of rearming and restriking with this surviving force after their return from their first strike mission. There are two services which will be needed; namely, the probable replacement of the nuclear powerplants (in that the remote-handling base facilities for individual detailed powerplant maintenance will no longer be available) and the rearming of the aircraft with new weapons. Both of these services can be provided from mobile ground equipment and at locations which are variable and unpredictable. Any number of currently available landing and takeoff areas would do the job. This rearming and restriking problem is essentially no different from that with chemically powered aircraft.

6. Nuclear-aircraft—Lower total costs than the massive chemical system

As a final note on this matter of a nuclear-aircraft retaliatory force, let us take up the matter of comparative costs. The best information which I have, and which is based upon appropriately detailed study—is that the nuclear-powered retaliatory force will cost appreciably less than its chemically powered counterpart system. I recognize that this statement is hard to believe in these days of accelerating weapons obsolescence; the major factor producing this situation is the fact that our current manned retaliation system is enormously expensive. The cost advantage accruing to the nuclear-aircraft force is predominately due to—

(*a*) A larger percentage of aircraft airborne at all times; therefore, fewer losses on the ground and fewer aircraft required in total.

(*b*) A larger weapons-carrying capacity per aircraft; therefore fewer aircraft required.

(*c*) No tanker aircraft required.

(*d*) No bases required—foreign or domestic, for the basing of the tanker aircraft.

(*e*) No complicated chemical fuel logistics and staging required at a wide number of bases—foreign or domestic.

(*f*) Considerably fewer bases from which the manned retaliatory force would need to operate.

And, interestingly enough, none of the above cost elements have even stopped to consider—

(*a*) That chemically powered aircraft can't even do the job if they are forced, as predicted, to attack at low altitudes where their range is drastically limited.

(*b*) That omnidirectional nuclear-aircraft will suffer fewer losses using low altitude penetration than will their chemically powered brothers at high altitudes—again acting to cut down on the total number of aircraft required.

Practically all of the foregoing reasoning has concentrated in the area of continuing to pose a real threat of retaliation as a means of making the instrument of war appear unprofitable for a potential enemy. While this area alone testifies as to the potential usefulness of nuclear-aircraft, the story does not end here.

STATIC DEFENSES ENCOURAGE CIRCUMVENTION

At numerous times during the history of the world, countries have based their longevity upon static, immobile means of defense. The Chinese Wall, the Maginot Line and, now, the DEW line have all acted to create the popular impression of impregnability. While the DEW line, supplemented by BMEWS equipment for ballistic-missile warning, is heavily useful for protecting the retaliation force, its coverage is still based upon the threat coming from a predictable direction and at a predictable altitude. If history teaches us anything, it is that a potential enemy is thereby provided with an incentive to circumvent the erected defense or warning line.

To me, the DEW or BMEWS line means two things:

1. That a potential enemy will strive to develop a weapon whose manner of attack will neutralize the usefulness of the erected defense.
2. That there is a supplmental need for mobile warning facilities which can react to various technological and political threats by virtue of their mobility.

SOVIETS ADVANCED IN NEUTRALIZING FIXED DEFENSES

Interestingly enough, the Russians already appear advanced in the development of weapons designed to neutralize the warning line. Their already recognized submarine force—improved in armament through the use of submarine-launched missiles—is in the process of being further supplemented by nuclear-aircraft. Both of these threats circumvent our erected warning line.

NUCLEAR-AIRCRAFT—USE AS A DEFENSIVE VEHICLE

If we are to be responsive to these threats, we should not respond by more massive, immobile narrow-range equipments but rather by systems whose versatility and mobility are matched to the changing and variable challenge. Air-orbiting nuclear-powered, radar-warning aircraft constitute one family of such systems.

ENDING COMMENTARY RE USEFULNESS OF NUCLEAR AIRCRAFT

I have now responded to two of the major comments which you are reported to have made relative to the ANP program, namely that "there is no usefulness that anyone could possibly see from such a plane" and that "there is no use of going into a field where the whole purpose could be to get a plane a few hundred feet off the ground."

As indicated by the foregoing analysis, there is plenty of "usefulness." The "few hundred feet" comment, as provided to you by your advisers, is a dangerously simple statement which completely misses the point of low-altitude penetration attack.

I realize that you may think I am proposing that the nuclear aircraft is an "ultimate weapon." Believe me, I am not. I do believe, however, that without them, we stand every chance of no longer having a stalemate in the strategic chess game.

II. Soviet ANP Capability

The third comment which you are reported to have made went to the effect that "there is absolutely no intelligence to back up a report that Russia is flight-testing an atomic-powered airplane." The question which prompted your reply was undoubtedly triggered by the article in the December 1 issue of Aviation Week which reported on the estimated status of the Soviet ANP program.

I would like to say, however, that the staff man who provided your text, was a hairsplitter of the first order:

1. Intelligence is available

In the first place, I am positive that there is intelligence on the relative state of the Soviet ANP program. Considering the strategic incentives which we have given them in the form of our DEW line plus their natural interest in showing evidence of technological supremacy, it should not be surprising if they were ahead of us. Maj. Gen. D. J. Keirn, in charge of the U.S. program, made a public statement to this effect a few weeks ago—adding that it would not surprise him if the Soviets flew on nuclear power within a year.

2. Characteristics of Soviet aircraft are significant

To a second point, I understand that there is significant evidence that a Soviet aircraft of the size and configuration described in the Aviation Week article has been sighted.

Using the article's overall design dimensions, and unless the Soviets have suddenly retrogressed in their ability to competently design chemically powered aircraft, there is little doubt but that this particular airframe is intended for use with nuclear powerplants. As a purely chemical airplane—even with advanced chemical turbojets—it is not a very good aircraft or weapons system.

As a side note, this is the first very large Soviet aircraft with pylon-mounted powerplants, it being the usual Russian design approach in such cases to bury their powerplants within the wing structure. This difference is particularly significant, however, because this is the direction you would take for easier later replacement of chemical with nuclear machinery and subsequent easier maintainability of the nuclear powerplants.

3. Existence of Soviet aircraft verified by their announcement

Subsequent to your December 10 press conference, on January 1, Moscow Radio, in a formal multilingual announcement, made two promises for 1959. These were that the Soviets would shoot a rocket to the moon and that they were going to fly a nuclear-powered "civil" aircraft during the next year.

I think that you will find that your intelligence agencies place a high credibility on this particular type of formal announcement, even without the fact that the Soviets—within 2 days—had a 50 percent scoring record.

MANY PUBLIC COMMENTS RE SOVIET PROGRAM ARE NOT TO THE POINT

I agree with your advisers, however, that the Aviation Week article presented no concrete evidence that this Soviet aircraft currently has nuclear powerplants installed. To the contrary, it is difficult to believe that any nuclear engine is currently installed within the comparatively small engine nacelles indicated on their drawings.

Whether or not this aircraft has actually flown on nuclear power—as questioned by your advisers and provided in their text for your use, is not really to the point.

It does not take any classified information to realize that if the United States started today on its prototype-aircraft program for ANP purposes, it would be approximately 3 years before any substantial chemically powered flight-test program on the aircraft would take place. As far as the relative airframe programs are concerned, therefore, we now have a pretty good fix on relative progress.

Sightings of this Soviet aircraft, of course, do not necessarily testify as to the state of progress in the Soviet nuclear powerplant program. Some criticism of the news article takes this direction—with the additional inference that the Soviet nuclear powerplant program is probably only to follow with an installed powerplant at a much later date. Even if this opinion is partially true, as it would be for any such program where the approach must be to take logical sequenced steps, it is a defensive comment and underestimates Russian tech-

nological competence in those areas where they really apply their effort. Certainly it does so if you believe, as I do, their January 1 announcement.

ENDING COMMENTARY RE SOVIET ANP CAPABILITY

Completely aside from all of the above, however, I join you in the belief that just because some other country is doing something is no reason for the United States to undertake a similar program in the same direction. That which the United States needs to accomplish should be tailored to its particular situation and to the particular objectives which it must reach in order to survive and prosper.

While I have already adequately dealt with some of the unique usefulness of nuclear-powered aircraft within part I, there are other questions and subjects which need to be discussed.

It is for this reason that I would be irresponsible if I stopped here. Going by the theory that better understanding cannot but help in the evaluation and decisionmaking process, I would now like to turn to the other issues which are raised by this general subject.

III. The Promise and Status of the U.S.–A.N.P. Program

In the foregoing pages, I have already laid a foundation with respect to the promise of the U.S.–A.N.P. program. We have dealt with—

(*a*) the property and versatility and mobility;
(*b*) the airborne alert-force concept;
(*c*) the manned nuclear-aircraft retaliatory mission;
(*d*) low-altitude penetration for reconnaissance and bombardment;
(*e*) the freedom from chemical-tanker logistics;
(*f*) the freedom from foreign-basing restraints;
(*g*) the reduction in the number of bases required;
(*h*) the inherently-large load-carrying capacity of nuclear-aircraft;
(*i*) the cost implications due to increased simplicity in the total manned retaliatory system; and
(*j*) the air-defense potential of nuclear-aircraft warning systems.

PROMISE SIMILAR TO THAT OF NUCLEAR-SUBMARINE—BUT MORE REVOLUTIONARY

In many respects, this identified promise for the nuclear-aircraft sounds much like that popularly assigned to the nuclear-powered submarine. A pure extrapolation here, however, would undershoot the mark.

The nuclear submarine providess quite a revolution over its diesel-electric-snorkel predecessors but, in terms of the relaative gain in total systems simplicity, the revolution in the air due to the nuclear-aircraft is of a much higher order of magnitude. By "total system" I mean the vehicle itself, its weapons, range, lethalness, vulnerability and the total complex of logistics and communications which permits it to do its job.

Compared to the submarine, nuclear-aircraft have a more massive effect on these logistic parts of the overall system which, in the aircraft's case, constitute a very major part of the whole.

The promise, moreover, does not stop here.

NUCLEAR-AIRCRAFT PROGRAM ADDITIONALLY IMPORTANT

The U.S.-A.N.P. program for manned-nuclear aircraft is important beyond the high value of its initial applications; this additional importance is due to the following:

1. Much technology transferable into space vehicles

The basic technologies of the manned nuclear-aircraft program are transferable and/or expandable into the nuclear-missile, heat-transfer nuclear-rocket and nuclear-powered space-vehicle areas.

2. Reason to believe aircraft must precede space vehicle

There is serious reason to believe that the United States will never proceed on sure footing into the more exotic nuclear-space-vehicle regimes until it has learned how to live and operate with manned nuclear-aircraft program. The king-sized step otherwise required appears indigestible from a practical mobilization and technological point of view.

3. Technology in forefront of nuclear reactor field

By the very nature of its effort in the area of comparatively lightweight, high-performance nuclear machinery, the A.N.P. powerplant program is automatically working in the forefront of nuclear-reactor technology, with resulting long-range ramifications in the atomic-electric field.

THIRTEEN YEARS NOW INVESTED

As you know, 13 years have now been invested in the aircraft nuclear propulsion program. With a modest beginning in 1946, feasibility studies into 1951 resulted in the conclusion that the application was feasible and deserving of development effort.

It is interesting to note that studies made during this feasibility period predicted the amount of time and money which would be required to do the job.

The predicted time has now been exceeded; less than half of the predicted amount of money has thus far been spent. In periods of national emergency, we have rightfully excused the trading of more money for less time; in consideration of the threat now around us—I wonder if going so far in the other direction (trading more time for a lesser expenditure per year) makes real sense.

With engineering development beginning in 1951, the program was directed toward a "flying-test-bed" application in which the initially flyable powerplant would be tested within a worked over and modified B–36 aircraft—the aircraft retaining its normal chemical powerplants in order to carry the nuclear powerplant aloft for testing purposes. This is normal practice with new aircraft powerplants and is practiced with chemical turbojets today.

NEAR CANCELLATION IN 1953

But what hapened? In 1953, the program was cut back (and nearly canceled in total) because the B–36 wouldn't fly high enough or fast enough to make it a miltary weapon—something which this B–36 was never intended to be in the first place. You may remember the word "shitepoke" which was a term of endearment provided by he Secretary of Defense at that time.

COULD HAVE FLOWN BY NOW

It is my firm opinion that had this cutback step not been taken in 1953, we would be flying a nuclear-powered aircraft today.

In consideration of what the Soviets show every sign of doing during this next year, we may live to massively regret this 1953 decision.

STILL NEED AN AIRCRAFT IN THE PROGRAM

At the present time, however, we have yet to go through this flying-test-bed stage—or its equivalent using an experimental aircraft. It is absolutely vital that this step be taken at the earliest possible moment.

The way support seems to be leaning in 1959, however, this event is still some years away.

Don't get me wrong.

The decision in 1953 of heading towards a better airframe for initial testing of the powerplant was not a bad idea.

It is just that—

1. at a point practically 6 years later, we have yet to even commit for the airframe part of the program; and
2. the announced reason for making this 1953 decision did not reflect any sophisticated understanding of aircraft powerplant development philosophy—or normal research and development practices.

EIGHT YEARS OF ENGINEERING DEVELOPMENT

Actual powerplant development has now been proceeding for practically 8 years, with full-scale reactor and reactor-turbojet-systems tests in process since 1956. Considerable airframe studies have taken place intermittently and at a variable pace during the same period.

During 1954–55, the Air Force—undoubtedly remembering its 1953 experience—began to clothe the ANP development effort in the mantle of a weapons system. It must be remembered that it was the fashion of the day (particularly

since 1953) that if more money was needed to get the job done, the only way it would be forthcoming was to "prove" that the project was going to result in something which flew higher and faster or carried more or what have you.

UNIQUENESS OF INITIAL NUCLEAR-AIRCRAFT CAPABILITIES NOT RECOGNIZED

This originally visualized weapons system (called 125–A) was to do everything that regular chemically powered aircraft could do—and then some—rather than harnessing the particular and special capabilities of nuclear propulsion.

While this 125–A affiliation was undoubtedly on shaky ground from the start, due to nuclear propulsion trying to compete initially with the best of chemical propulsion in the chemical regime's own backyard, it did accomplish one very beneficial result. Some additional money was made available—at least enough to really get a leg up on the powerplant development work.

Since then, some real powerplant development progress has been made.

DEVELOPMENT READY TO PROCEED AT A FASTER PACE

The powerplant development work is now at a stage where it is ready to proceed at a faster pace. It is true that some solutions in detail (as opposed to "feasibility") are required, but these are the reasons why the development is necessary in the first place.

Then he goes on, and I quote:

"In today's environment, I get the impression that the only way to really get development support is to prove that everything is already comfortably in position, with all challenges answered in minute detail. In such a position, there will be development money made available when, if such was really the case, the weapon should be in quantity manufacture."

He points out that:

"Today's situation on the nuclear-aircraft program is similar to that which prevailed on the missile programes 3 to 5 years ago. At that time, development work was accelerated on propulsion and guidance aspects of the work; today, we are just beginning to see signs that we will have operational missile systems over the next 2 to 4 years."

The same situation can prevail for nuclear aircraft.

CAPABILITY-IN-DEPTH AVAILABLE

When I say we are ready to proceed, I am not referring to an informal group of scientists working in the laboratory. I am talking about a balanced and sizable organization of scientists, design engineers, manufacturing engineers, and test engineers—all backed up by a complex of pilot-line manufacturing facilities, raw material sources, subcontractor installations, and hardware vendors.

PROMISE OF THE FUTURE IS GREAT

Of considerable significance to the nuclear-aircraft program is the fact that the initial powerplant and the initial application can now be clearly seen to be the first of a family of improving performers. Enough is known about the designs further back in the conceptual and preliminary design stages to predict with certainty that the initial hardware approach will improve in performance even beyond that which is now called the requirement.

He follows this up by making this important point:

"The vacillator and the fence sitter wants to wait for the 1985 model although the 1959 model will still manage to outdistance anything on the road.

"It is my conviction, however—and I have lots of knowledgeable company—that failure to buy the 1959 model is not going to result in any improvement in what the 1985 model will do in its time.

"As a matter of fact, if we delay in facing up to the full-scale development of what can be done today, the 1985 capability won't come out until the year 2000, if ever."

"CAMAL" MISSION A UNIQUE APPLICATION

One of the main reasons behind the fact that program acceleration now makes such sense is the unique concept of the CAMAL mission, as described in summary fashion in part I. This approach not only takes perfect advantage of the unique properties accruing to nuclear propulsion; it also turns out to offer

a uniquely different and extremely valuable weapon for the defense situation which faces us.

Further, this approach will not only do a real job of using the initially developable airframe and powerplant, but will also improve in performance and capability as the second cousins come out of the developmental brooder.

Then he adds:

"Let's face it. Nuclear-powered aircraft are inevitable. The sooner we get about really facing up to the job in total, including an airframe, the sooner they are going to be a valuable weapon in our arsenal."

IV. Criticisms of the U.S. ANP Program

With all of the promise and all of the progress which I have talked about thus far, you may well ask: "Where has all the trouble been coming from?"

Let's take a look at the collection of critical comments which have been made against the nuclear-aircraft program, examine them in some detail, and see if some pertinent conclusions can be reached.

Criticisms of the U.S. ANP program can generally be classified into three broad areas; these are:

A. Applications (the use to be gained).
B. Technology (the state of the development).
C. Administration (program decision problems).

Let us deal with each of these areas in sequence.

APPLICATIONS—ORIENTED CRITICISMS

Critical comments in the area of "applications," or the use to which aircraft nuclear propulsion would be put, can be listed as follows:

"The aircraft is too big or too slow."

Here we find the man who wants to go "higher and faster" all of the time, regardless of where he should be. I can understand the necessity for going "higher and faster" with part of our retaliatory force—just to force the Soviets to defend against such an attack—but less and less of our total force will be able to penetrate in this way.

This critical comment therefore fails to recognize that the survival of aircraft at high altitudes and even very high supersonic speeds will become increasingly less probable with the passage of time. Attrition in this regime will be markedly higher that that at extremely low altitudes and respectable subsonic speeds. Chemical aircraft can't do the latter. (See pt. I.)

On the comment of "size," initial nuclear aircraft will be no bigger, and possibly smaller, than today's larger chemical aircraft. They may weigh more—i.e., be "denser" aircraft—but I can't see where the point is. As a matter of fact, nuclear power may very well cause a complete reevaluation as to what constitutes the "optimum size of an airplane."

"The aircraft would be easy to shoot down."

This is probably the same gentleman who wants to go "high and fast." He doesn't understand the overwhelming defensive requirements superimposed by an omnidirectional, low-altitude penetration attack. He doesn't realize the magnitude of investment required for a low-altitude, radar-warning net and the associated defense missiles and air-defense aircraft (which are range limited at these low altitudes).

In short, he hasn't recognized that for a country with the land mass and perimeter of the Soviet Union he now has the weapon of economics (and possible bankruptcy) on his side.

"We don't really need a nuclear aircraft."

This gentleman either doesn't understand anything mentioned in part I or else he is a "saturation war" man. This latter breed says if anything starts we will just plaster everything and everywhere, using an immense number of missiles carrying atomic and hydrogen warheads. This way, he says, we will be sure and hit everything worth hitting.

This reasoning is fallacious on two counts: First, the rest of the world would be in danger of becoming uninhabitable; and, second, I don't believe the United States will ever choose to adopt this inhuman and reckless defense posture.

It has been said: "As soon as men decide that all means are permitted to fight an evil, then their good becomes indistinguishable from the evil they set out to destroy."

"The application being worked on is the wrong one" (regardless of which one is being worked on).

Here is the man who says that we should make up our mind—over and over again. Or perhaps he is stating that he doesn't want to do anything until everybody decides to do it his way. I really don't know.

I only know that the application chosen is a particularly valuable one, and that after satisfying this first step there will undoubtedly be others.

"I don't understand it." We have found an honest man; he is one of the gentlemen for whom this letter is written.

TECHNICALLY ORIENTED CRITICISMS

Critical comments in the area of "technology," or the "state of the development," are fairly represented by the following:

"An airborne reactor is too dangerous."

What this gentleman is saying is that "aircraft are dangerous." As far as the aircraft's crew is concerned, a reactor with its radioactive parts is less dangerous than several tons of flammable aviation fuel.

It is true, however, that experimental and perhaps operational nuclear aircraft will have to fly in specified corridors when over land to eliminate the danger of a possible crash in populated areas. This will undoubtedly be a function of the demonstrated reliability of the total aircraft system as well as the appropriate selection of locations for the operational bases. Significant study has already been devoted to this problem with encouraging findings.

Please understand that what is being talked about here is not an atomic explosion but the potential spillage of radioactivity should an aircraft crash.

A fair comment in this area would be: There are some risks; they are the types of risks which can be overcome by operational procedures and system reliability; they are a very long way from being sufficiently large enough to give up what the aircraft has to offer as a military weapon.

"The radiation is too high; the crew can't last."

Without going into a mass of technical data—much of which is classified—let me just state that current design of the system is based upon each operational crew flying for a very appreciable number of days each year, for a very appreciable number of years, and still at the end of the period have received no more radiation exposure than they would have had they spent those years working in an AEC industrial laboratory. And please believe me, this is just about as radiation safe as you can get—anyplace—anywhere.

"The reactor temperatures aren't high enough."

This is the comment of the man who wants to wait for the 1985 model, as mentioned in part III. The temperatures are high enough to do what needs to be done first; they promise to be higher by the time they need to be higher. If we wait until then before we accomplish development testing needed now, the whole program will suffer and be delayed.

As a side comment, there is little if any doubt but that as the development progresses the designed temperature capability of the reactor will come to put extreme engineering pressure on the designers of the remaining parts of the powerplant. Believe me, this is plenty high enough.

"It isn't being done the way I would do it."

No comment appears necessary.

"I don't understand it."

The people who have already built and test operated reactor-turbojet systems do understand it, and they'll talk to anyone who has a security clearance and a desire to listen. As a matter of fact, they won't let you get away.

ADMINISTRATIVELY ORIENTED CRITICISMS

Critical comments in the area of "administration," or "making program decisions," can be summarized as follows:

"Aren't ready; wait until next year when things will be 'better.' "

Here is the administrator, either technically or politically motivated, who either wants to wait for the 1985 model or who is too tired to fight for what he believes is right. Perhaps he just doesn't want to risk his position by being a nonconformist in a bureaucratic world. Whatever he is, he is not doing a responsible, risk-taking, managerial job.

"It's too expensive."

Too expensive? Relative to what?

Individual nuclear aircraft will be more expensive than their individual chemical-aircraft brothers, just as nuclear submarines are more expensive than conventional submarines. But the total cost of doing the overall larger and necessary job will be less through the nuclear application.

This is the gentleman who either doesn't understand the cost situation, or who equates a currently positive bank balance with lower overall long-run costs. I will have more to say about this later.

"The other Government agency hasn't made up its mind."

This is perhaps better described as the "Alphonse-Gaston" phenomena. It is the frame of mind which says that the only good decision is the unanimous decision. I firmly believe that many unanimous decisions, appropriately watered down and denatured to achieve unanimity, are the worst kinds of decisions. True, they are better than none at all, but unanimous decisions or no decisions appear to me to be the only kinds of decisions the ANP program has had.

"Government leadership on the program is too weak."

Here is a crackerjack. This is hard to believe but some Government representatives have actually withheld enthusiasm for the ANP program because they felt that the Government leadership on the program wasn't strong enough. I can only say either discard the criticism or fix the situation; don't use it as a reason for continued vacillation.

CRITICISMS RAISE MAJOR QUESTIONS OF PROGRAM ADMINISTRATION

All of these critical comments raise major questions.

It is evident that little understanding exists, that there are overlaps in responsibility and authority, that people have decided that it is much more politically comfortable to be against something or to be silent than it is to have faith and conviction and to fight for what they believe.

Let's take a look at some of these national problems of administering the U.S. ANP program.

V. The National Problems of Administering the U.S. ANP Program

Many administrative problems of the U.S. ANP program tend to be peculiar to it, and to it alone. These are disturbing.

Many additional problems of the U.S. ANP program are shared with many other national defense programs. In that these have an even larger effect, they are even more disturbing.

We are trying to compete technologically with inadequate attention to the creaking administrative system for doing the competitive technological job. Our administrative machinery must be as up to date as the technology which it energizes.

Let's take a look at some of this machinery.

PROBLEMS PECULIAR TO THE ANP PROGRAM

Those major administrative problems which tend to be peculiar to the ANP program can be described as follows:

Multiple offices, agencies, and departments

I would conservatively estimate that there are well over 60 separate and effectively independent offices, agencies, and departments in the U.S. Government which have a measurable influence over the rate of progress of the ANP program. While there is currently existing an ANP office, its relative authority falls far short of that necessary to accomplish the job.

For example, in addition to the ANP office, there are:

1. The AEC (including the Division of Reactor Development, multiple staff groups, various committees, etc.).
2. The USAF (including the Air Research and Development Command, the Air Materiel Command, the Strategic Air Command, at least 15 different staff groups, various committees, study groups, etc.).
3. The USN (including the Bureau of Aeronautics, the Office of Naval Research, staff groups, committees, etc.).
4. The DOD (including the Deputy Secretary and his office, essentially all of the Assistant Secretaries and their offices, various staff groups, committees, study groups, etc.).
5. The NASA (NACA)—(I haven't figured this one out yet).

6. The Bureau of the Budget.
7. The Central Intelligence Agency.

Conflicts from the contributing Government departments

In the case of the Air Force, the issue is mostly a question of decision making and delegating authorities to do the job. In many major respects, the decision mechanisms (even for many minor matters) only reside at the very top of the USAF organization. This means that even if major policy decisions are made, many of the individual implementing decisions either have to go bubbling back to the top or be laboriously handled through satellite staff or administrative offices.

The contributions of the Atomic Energy Commission have been very real and valuable. Although the AEC also suffers occasionally from bureaucratic strangulation, you can usually count on them to make a real college try. The AEC's responsibility, however, has been greatly complicated by the problems which the Air Force has had in making up its mind in the face of severe budgetary pressures.

The Navy definitely wants a nuclear aircraft program. But unless they can have a nuclear aircraft as soon or sooner than the Air Force, I am convinced that they will do everything in their power to destroy the Air Force program.

No strong governmental program leadership

The issues of "multiple offices, agencies, and departments" and "conflicts from contributing departments" would be less severe were the ANP program vigorously led by a program manager with appropriately delegated responsibilities and authorities. This has not been the case.

With all due respect to Maj. Gen. D. J. Keirn, he has not received necessary support and authority to do the job (regardless of various surface changes made).

Even if he had received such delegations, however, he is too much of a gentleman to knock heads together when the going gets rough.

With so many different people going in so many different directions, somebody has to be able to say "follow me" and "keep in line."

PROBLEMS SHARED WITH OTHER DEFENSE PROGRAMS

There are other administrative problems which the nuclear-aircraft program shares with other defense programs. Since some of these are fairly well understood, I will only comment on those which appear to me to need some more understanding.

Remote decision makers have meant the usual (easy way out) use of review committees

The problem here is that most, if not all, review committees are also remote. How a group of men can spend 2 to 4 hours, at intervals of 18 to 24 months, talking with the people who are doing the job, and then say they have "reviewed" the program, is beyond my understanding.

Depending upon their length of time in their positions, most committee members are previously committed to the support of other programs. Since these members are well aware of the pressures of funding, they are not going to support anything which looks as though it will steal support from something they feel they have already staked their reputations on.

Many committee members are simultaneously in other positions, either in Government or industry, where they can advance competing or delaying proposals of their own. Don't misunderstand; most competition is a good thing. It is just that here is an avenue for the guy who says "why don't you do it my way?" He can really delay decisions; after all, he is a member of the committee who will review the "new idea" he has just proposed.

There are those who say that the use of review committees is a fundamental part of the process of democratic government. This is hard to defend; we had democratic government long before we had review committees. The use of such committees is, in my opinion, a fundamental symptom of faulty organization. If policymakers are so enmeshed that they can't get closer to their decision-making job, then their positions are too big and should be split into smaller responsibilities. Adding extra layers of organization doesn't help either, and there are plenty of them.

High security classifications and multiple security systems

It should be no surprise that the extent and height of security classification would come under criticism. Enough has been said about this elsewhere.

What is even more difficult to understand is why we continue to need both a military security system and an atomic energy security system. They duplicate one another in the military reactor field and only manage to get in one another's way to the detriment of everything else.

Excessive checks and balances

Many laws passed by Congress and many other administrative laws created and installed by Government agencies are based upon the premise that it would be horrendous for anybody to make a mistake. "Mistakes must be prevented."

The result is that we now have erected an enormous, overlapping, and detailed system which goes significantly beyond the original intent of checks and balances and effectively achieves partial strangulation. Harmful program delays are inevitable.

The tremendously large number of people who can say "No" and the effective absence of anyone who can say "Yes"

I believe that I have adequately commented on this subject on previous pages. It is a shorthand description common to many of our major administrative problems.

Extreme competition among the military services.

Absence of vision re something different. The solutions to problems and the predictable future.

Complacency re the Soviet threat.

The concept of business as usual.

VI. Recommendations for Action

In consideration of what I have already said, my recommendations should come as no surprise.

The United States desperately needs and must regain the initiative in all fields. In the military area, initive should be equated to the concept of mobility and mobile forces, as opposed to relying almost solely on static concepts.

The United States should adopt the nuclear aircraft as one prime contributor to the operating concept of mobility; the implementation of this decision requires at this time:

1. The strengthening of Government program leadership in the nuclear-aircraft field.
2. Growth in support for the powerplant program.
3. Initiation of the prototype airframe program.

VII. Concluding Remarks

In closing, I want to quote some extremely pertinent remarks by others on the general question of the defense posture of the United States.

Early in 1958, the Rockefeller Report (from panel II) on "International Security—The Military Aspect" had this to say:

1. "The basic requirement * * * is a retaliatory force so well protected and numerous that it can overcome any defense."

2. "The hard core of this striking force, whether based at home or overseas, must be *continuously alert*, fully armed, and *as secure as we can make it against* destruction or neutralization by *surprise attack*." [Italic mine.]

3. "It is therefore imperative that * * * we develop units which can intervene rapidly and which are able to make their power felt with *discrimination and versatility*." [Italic mine.]

4. "*Accelerated research and development support should be provided* for all key programs including missiles and *advanced reconnaissance systems*." [Italic mine.]

5. "The panel is convinced * * * that * * * increases in defense expenditures are essential and fully justified. * * * We can afford to survive."

6. "When the security of the United States and of the free world is at stake. cost cannot be the basic consideration. The cold war cannot be won and a hot war cannot be avoided without a major effort. This is clearly not the time for complacency. * * * What is required throughout the country is an attitude of sustained and informed determination."

Late in 1958 the nonpartisan, nonpolitical National Planning Association issued a significant warning:

"The dismal fact is that unless the United States takes many measures not contemplated in its present military program, the moment is approaching when (the assumption that U. S. retaliatory power is an effective deterrent to Soviet military action) will have lost its validity.

"* * * If steps are not promptly taken to vastly strengthen American retaliatory capability, the Soviet Union in the not distant future will be in a position, by the use of ICBM's and IRBM's armed with thermo-nuclear warheads, to inflict so strong a blow on SAC bases in the United States and Europe that retaliation by the United States would be held within limits acceptable to the Soviet Union."

Any feeling of complacency in this defense area must be based upon a judgment that—

1. Communism is self-destructive.
2. An internal collapse of the Soviet system is inevitable.
3. Only "reasonable" retaliatory strength is required.

I cannot identify any compelling evidence which supports this judgment.

I am sure, however, that the overwhelming majority of Americans are behind you in the mounting battle to balance the national budget. I believe that your leadership in the fight to eliminate deficit financing makes a real contribution to the noninflationary economic growth required over the next decade.

The problem then is one of making choices.

The Rockefeller report (from panel IV) on "The Challenge to America: Its Economic and Social Aspects" emphasized this problem of choice, concluding that the United States could afford all defense essential for survival if it decided to do so.

In my opinion, the real danger lies in an underestimation of the American people. They are willing to pay for more national security, even if this means reduced Government services in other less-immediate areas.

The proposed Federal budget for fiscal year 1960 has already taken at least part of this willingness into account.

But does it go far enough?

I cannot help but conclude that it does not. I believe that an overwhelming majority of American citizens would prefer to be absolutely sure that the amount of national defense available is adequate for security, rather than risk even a momentary period of potential collapse in retaliatory deterrent.

The nuclear-aircraft program can help to prevent this potential collapse.

Respectfully,

JOHN W. DARLEY, Jr.

CINCINNATI, OHIO, *January 14, 1959.*

[From Aviation Week, Dec. 1, 1958]

THE SOVIET NUCLEAR-POWERED BOMBER

On page 27 of this issue we are publishing the first account of the Soviet nuclear-powered bomber prototype along with engineering sketches in as much detail as available data permits.

Appearance of this nuclear-powered military prototype comes as a sickening shock to the many dedicated U.S. Air Force and naval aviation officers, Atomic Energy Commission technicans, and industry engineers who have been working doggedly on our own nuclear aircraft propulsion program despite financial starvation, scientific scoffing, and top-level indifference. For, once again, the Soviets have beaten us needlesly to a significant technical punch.

While this Soviet achievement is a truly remarkable feat, it is not beyond the technical state of the art in our own nuclear aircraft propulsion program. The difference lies rather in the top priority and steadfast support accorded the Soviet program by its top political leadership and the technical timidity, penny-pinching, and lack of vision that have characterized our own political leaders' attitude toward the goal of nuclear-powered aircraft for both military and civil purposes.

This is a story that has become all too familiar to Americans in recent years, punctuated by the Soviet triumphs with the first medium-range ballistic missile in production and military deployment; the first successful ICBM firings followed by an ICBM production rate that is now more than 15 per month, and

the trio of sputniks. This also could be the epitaph carved on the tombstone of this country's genuine technical development capability if we continue much longer on this course.

We are sure that there will be the usual chorus of good gray voices from high official places attempting to pooh-pooh the existence of a Soviet nuclear-powered bomber prototype and coining smooth weasel-worded phrases to deprecate its significance even if its existence is finally admitted, as finally it must be. For the basic facts on this Soviet aircraft are known in official circles both here and abroad.

The credibility of the same gray voices has, of course, diminished in recent years because they used the same tone and phrases to sooth the country before the appearance of Soviet nuclear weapons, intercontinental bomber, supersonic fighters, medium-range missiles, the ICBM, and the sputnik.

Maj. Gen. Donald Keirn, chief of the USAF–AEC aircraft nuclear propulsion program, virtually let the cat out of the official bag in the question period after a speech in Washington last month by admitting that it would not surprise him if the Soviets flew a nuclear-powered aircraft before the end of 1958. This was like placing a bet on a horse race after you have watched it finish through binoculars and have found a bookmaker who doesn't have a phone.

With an acute awareness that the first world-wide demonstration of the Soviet nuclear plane would generate a major political blast, General Keirn also pointed the finger of responsibility for our own slow progress at the sources who are really at fault. These are the anonymous scientists headed by James Killian, scientific advisor to the President, who operate under a heavy veil of official secrecy and only last spring vetoed a military-industry proposal to accelerate nuclear aircraft development on the basis of promising technical achievement.

Although not mentioned by General Keirn, former Secretary of Defense Charles E. Wilson also must answer for his jeering characterization in 1957 of an atomic-powered plane as a shitepoke, a bird that has a long neck, big body and can fly, but not very fast, and for his 1953 attempt to wipe out the entire aircraft nuclear propulsion program by cutting off its development funds. The late Harold Talbott, then Secretary of the Air Force, circumvented this Wilson order by diverting some hidden USAF funds to the program. AEC also maintained its support.

Since word of the Soviet nuclear-powered aircraft began filtering through the Iron Curtain, the Pentagon has hastily revived an active program aimed at a nuclear-powered military aircraft known as the CAMAL project. Mission of this aircraft is described by General Keirn on page 28. Think of the political and military significance of even a small fleet of nuclear-powered military aircraft that, as General Keirn described, can cruise indefinitely off the territorial limits of the United States, maintaining a continuous airborne alert and warning system combined with the capability of quick launching of missiles with sufficient range to penetrate 1,000 miles or more and following up this attack with a high-speed, low-level penetration well under and around radar defenses to obliterate key targets missiles cannot locate. It takes no military expert to appreciate the value of this apparatus in the hands of an aggressive, ambitious political dictatorship bent on world conquest.

The development of a nuclear-powered military aircraft involves much more than just producing a satisfactory powerplant, and this is a phase in which we lag even further behind than in engine development. Every time the financial pinch was applied to the nuclear aircraft program, those in charge, of necessity, starved aircraft systems development to keep the powereplant research alive.

Thus, with the Soviets now in the initial flight testing of a nuclear-powered military prototype and the Air Research and Development Command scheduled only this month to make a decision on prototype construction of a similar USAF weapon system, it is clear to even the most conservative technical analysts that we are at least 4 years behind the Russians in this critical area. Development of such a new and technically radical weapon system to full military capability is a long, painstaking, and failure-studded process on both sides of the Iron Curtain. But with such a clear-cut lead, we can expect the Soviets to exploit their nuclear-powered aircraft for political warfare long before it has developed a sound military capability. There already are indications that a nonstop, nonrefueled flight several times around the world is being planned by the Soviets with this type aircraft. And how much political force will an event such as this impact on our allies, the neutrals, and our enemies?

During the past few years, we have heard much from our political leaders on how much we can or cannot afford for the defense of this country.

These were the same years that we have been belabored with vigorous efforts to cut the strength of our military forces in being and jeopardize our military future by saber slashes through the research and development budget.

These were the same years the Soviets appeared first with their huge turbojet and turboprop gas turbines, their medium-range ballistic missiles, ICBM, and sputniks.

In view of these Soviet technical achievements, it is more pertinent to ask: How much longer can we afford this kind of leadership and still survive as a free nation?

ROBERT HOTZ.

[From Aviation Week, Dec. 1, 1958]

SOVIETS FLIGHT TESTING NUCLEAR BOMBER

ATOMIC POWERPLANTS PRODUCING 70,000 POUNDS THRUST ARE COMBINED WITH TURBOJETS FOR INITIAL OPERATIONS

WASHINGTON.—A nuclear-powered bomber is being flight tested in the Soviet Union.

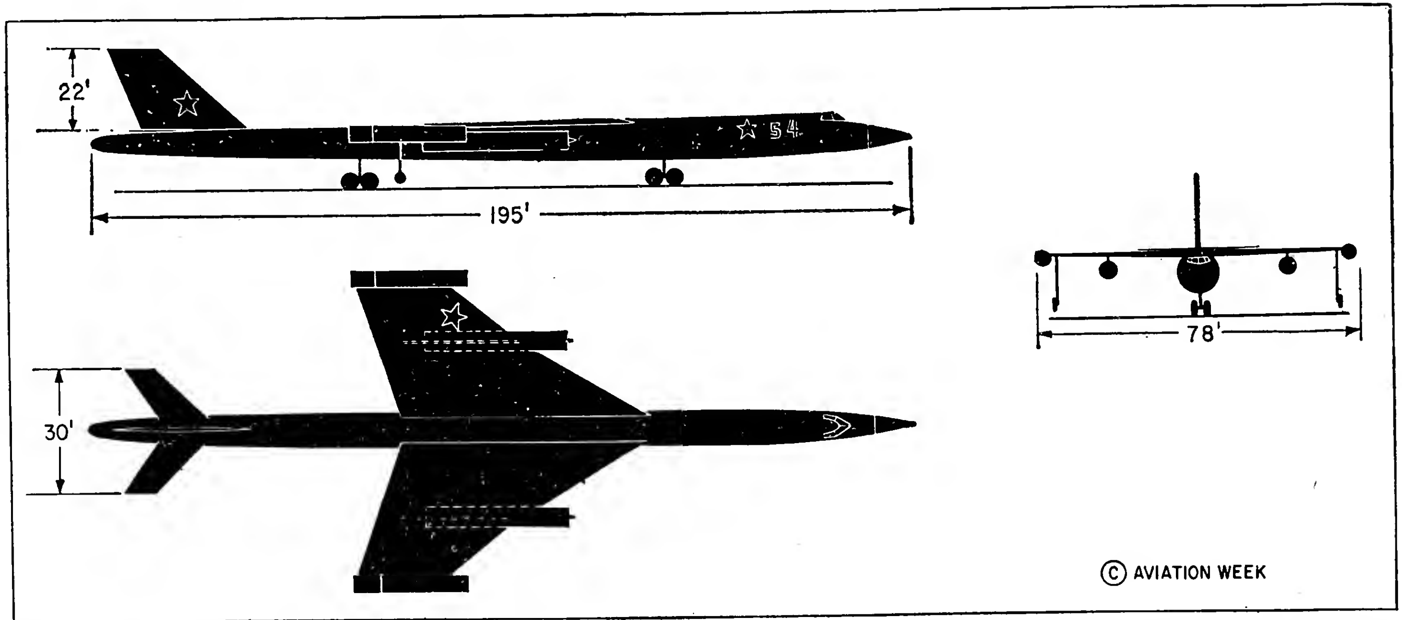
Completed about 6 months ago, this aircraft has been flying in the Moscow area for at least 2 months. It has been observed both in flight and on the ground by a wide variety of foreign observers from Communist and non-Communist countries.

In its initial flight testing, the new aircraft is powered by a combination of nuclear and conventional turbojet engines. Two direct air cycle nuclear powerplants are housed in 36-foot-long nacelles slung on short pylons about midway out on each wing. These nuclear powerplants, with 6-foot-diameter air intakes and using small but high power reactors to replace the combustion chambers in the turbojet cycle, produce about 70,000-pound thrust each.

They are supplemented by two conventional turbojets installed in wingtip pods fitted with short afterburners to provide about 35,000-pound thrust each for takeoff performance. The conventional, chemically fueled turbojets are used primarily for safety purposes during the early flight test program of the nuclear powerplants. In later versions of the aircraft, they may be retained for high-speed dash performance or replaced by two more nuclear powerplants after their reliability has been proved in flight.

The Russian nuclear-powered bomber is not a flying test bed in the sense that earlier U.S. Air Force and Navy programs had called for installing a nuclear powerplant in a conventional airframe such as the B-36 or Saunders-Roe Princess flying boat solely for test purposes. The Soviet aircraft is prototype of a design to perform a military mission as a continuous airborne alert warning system and missile launching platform similar to the USAF CAMAL project of which Convair and Lockheed are now making design studies (AW Nov. 10, p. 37). The CAMAL mission was recently described in detail by Maj. Gen. Donald Keirn.

In its present configuration with both nuclear and conventional turbojets, the Soviet aircraft has a performance capability in the high subsonic and low supersonic speed ranges with its range limited only by engine component life and crew endurance.



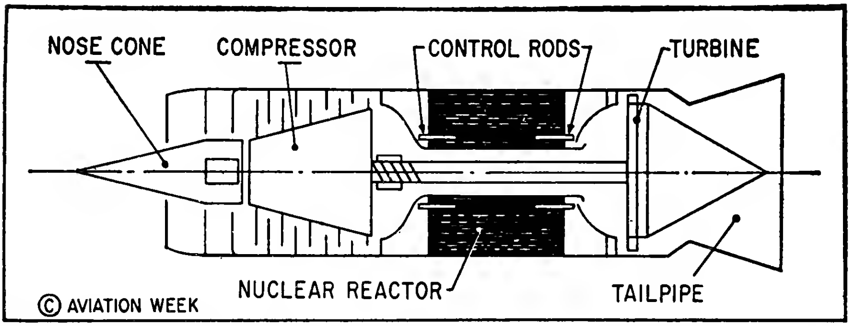
AVIATION WEEK ARTIST'S conception of how Soviet nuclear-powered bomber prototype looks in three-view. Note bicycle main landing gear with outriggers folding up into wing from wingtip and tin high-speed airfoil. Nuclear powerplant air intakes are approximately 6-ft. in diameter. Radiation shielding details are not available, but divided shielding concept is used with heavy shielding around nuclear powerplants and additional shielding protecting crew compartments.

The Soviet nuclear-powered plane has a fuselage about 195 feet long and a 78-foot wingspan. The delta-type wing is sweptback on both leading and trailing edges. From an initial angle of 60° sweepback at the wing root, the leading edge changes to about 55° sweep at the inboard engine pylon mounts and beyond to the wingtips to produce a "cranked" effect familiar on British bombers such as the Handley Page Victor and Avro Vulcan. Trailing edge of the wing is swept about 15°. This delta-type wing uses a relatively thin, high-speed airfoil confirming eventual performance goals for this design in the Mach 2 speed area.

Vertical tail rises about 22 feet above the fuselage. It is a typical sail-type fin used by Soviet designers to insure good directional stability. Horizontal tail surfaces have a span of 30 feet and are swept back at about the same angle as the outboard wing panels. They apparently are kept well clear of the nuclear powerplant efflux both by placement high on the fuselage and by span length.

Aircraft has a gross weight of about 300,000 pounds and a wing loading of about 118 pounds per square foot.

The direct air cycle nuclear powerplant has been described in some detail in Soviet technical publications. In a text published last year by the Military Press



SCHEMATIC DIAGRAMS from Soviet technical source on a direct air cycle atomic turbojet. Nuclear reactor is used in place of normal chemical fuel combustion chamber with air and compressor shaft passing directly through reactor.

of the Soviet Defense Ministry entitled "Application of Atomic Engines in Aviation," the direct air cycle powerplant is described as follows:

"The simplest is a design that differs from the ordinary turbojet engine only in that the combustion chamber is replaced by a reactor.

"This simplest design permits obtaining the highest specific performance parameters. In this case, the air duct becomes a uniflow duct where the airflow through the engine is at all times parallel to the engine axis in a straight line so that hydraulic resistance is at a minimum.

"The air is heated directly in the reactor without an intermediate heat transfer agent. This simplifies the design and eliminates excessive heat loss. However, this design which is simple in principle, is exceedingly difficult to realize. The shaft connecting the turbine with the compressor has to pass through the reactor. Cooling the shaft under these conditions becomes a difficult, and actually the key, problem.

"The point is that the shaft not only becomes heated as a result of heat transfer from the hot reactor parts but considerable liberation of heat occurs within the shaft itself due to scattering and absorption of neutrons and gamma rays by the shaft material. So much heat is liberated in the shaft that cooling of the shaft changes from a simple engineering matter to a complex problem whose solution will govern the very possibility of developing an atomic turbojet engine on the basis of this 'simplest' design."

This direct air cycle nuclear powerplant represents the same approach pursued by the Aircraft Nuclear Propulsion Department of General Electric Co. under USAF and Atomic Energy Commission sponsorship since 1951 at facilities in Evendale, Ohio, and Arco, Idaho.

D. R. Shoults, general manager of the GE nuclear propulsion program, reported that actual operational tests at the Arco facility had "proved the feasibility of a direct air cycle aircraft propulsion system and demonstrated its performance." The Shoults report was made in a paper prepared for the Second United Nations International Conference on Peaceful Uses of Atomic Energy held last September in Geneva, Switzerland (AW Sept. 22, p. 55).

He described the results of operating heat transfer reactor experiment No. 1 (HTRE–1) during more than 100 hours of turbojet running on nuclear power without "any failures of any sort."

Shoults also reported that HTRE–1 determined the following:

Integrated performance of the reactor and turbojet engine in the powerplant system.

That overheating in portions of the reactor would not lead to local flow starvation and progressive overheating.

Integrity and life of key components of the system.

Ability to carry out extensive remote handling of raioactive components.

Control response of the reactor and its relationship to turbojet engine control.

Unanticipated problems and their possible solutions.

The approach to flight testing nuclear-powered aircraft both in this country and in the Soviet Union calls for initial operations on conventional chemical fuels to prove out aircraft systems and familiarize the crew with operational techniques. However, even in operational use of a nuclear-powered military aircraft, nuclear powerplants may be operated initially on chemical fuel until the reactor temperatures are sufficiently high for full power operation. Then chemical fuel combustion can be phased out and the turbojet permitted to operate on nuclear power alone. Similarly, on return from a mission the reactors would be shut down some distance from destination, with the return to base and landing again made on chemical fuels. For this type of operation, a chemical combustion system also must be incorporated in the nuclear powerplant package.

POWERPLANTS FLIGHT TESTED

Although much of the early flight testing of the Soviet nuclear aircraft has been conducted on conventional fuel and nuclear powerplants have definitely been tested in the air. Fission of 1 pound of uranium 235—most frequently mentioned in Soviet technical literature along with plutonium 239 as an airborne reactor fuel—will liberate about the same amount of energy as the burning of 1,700,000 pounds of gasoline.

There is no specific information available on the types of shielding employed on the new nuclear-powered aircraft but recent Soviet technical literature has been studded with brief but positive references to a major "breakthrough" in shielding techniques. Soviet technical literature emphasizes the concept of divided shielding with heavy use of stainless steel in the engine and aircraft structure to provide containment shielding for neutron radiation and another type of shielding protecting the crew quarters from gamma radiation. The extreme length of the aircraft fuselage also would be aimed at maximum separation of crew from the radioactive engines.

The podded installation is best suited to the direct air cycle type nuclear powerplant since its operation makes the entire turbojet engine radioactive. The pod would facilitate engine removal by remote control for ground radiological safety and make replacement of the powerplants relatively simple.

Taking a nuclear-powered military aircraft from the early flight test stage, through which the Soviet aircraft is now passing, to a fully operational capability for both airborne early warning and missile launching capability probably will require at least 18 to 24 months. A nuclear-powered aircraft requires extensive testing for other flight operational subsystems other than the powerplants and their operation under varying degrees and different types of radioactivity.

The current Soviet milestone in testing nuclear powerplants in flight in a military prototype is the result of a high-priority and financially well supported program stretching back through nearly 8 years of research and development.

High priority for the nuclear aircraft program was assigned during the current sixth 5-year program which began in 1956 and will end in 1960. During the past few years, Soviet technical and popular publications began a steady crescendo in their coverage of atomic aircraft powerplant developments in addition to marine atomic powerplants for icebreakers, submarines, and surface vessels.

This similar type of publication buildup has preceded every new major Soviet technical achievement, including the intercontinental ballistic missile and the sputniks.

As long as a year ago, there were brief but specific mentions in the Soviet technical press of successful ground testing of atomic aircraft powerplants. Recent speculative stories in the Soviet popular press suggest conditioning the Russian people to an announcement of a spectacular achievement by an atomic-powered aircraft in the near future, probably a nonstop, nonfueled flight around the world.

ATOMIC ENERGY IN AVIATION

BY

YU. N. SUSHKOV

All-Union Society for the Dissemination
of Scientific and Political Knowledge

(Translation)
Moscow, 1958

GENERAL ELECTRIC-AIRCRAFT NUCLEAR PROPULSION DEPARTMENT-CINCINNATI 15, OHIO

Introduction

The Soviet Union has achieved great successes in the areas of peaceful uses of atomic energy. One of the most significant dates in the historical development of atomic power is 27 June 1954 - the Soviet "first-in-the world" atomic power plant began operation. Successful operational experience in the first atomic power plant created the foundations for wide introduction of atomic power into the national industry. In the near future, it is planned to construct larger atomic power plants which have a total capacity of 2-2.5 million kilowatts. Work was started on the application of atomic energy for transport purposes. The atomic icebreaker "Lenin", which can navigate without refueling for 2-3 years, has already been launched.

When discussing the application of atomic energy in aviation, the following questions arise: Are atomic aircraft engines necessary at all? Do they have any advantages over ordinary engines? Is it possible to build reliable and non-hazardous atomic engines for aircraft? The development of aviation is characterized by a continuous growth of flight speed, range and altitude. However, up to the present time it has not been possible to build an airplane which has all of these capabilities at one and the same time. For example, an aircraft designed for high speed has to have powerful engines; but these engines consume much fuel and therefore the aircraft's fuel supply will soon be exhausted and its flight range considerably restricted. On the other hand, an aircraft designed for long range has to fly at an exactly predetermined speed, at which the fuel consumption for each kilometer of distance will be at a minimum; but this speed will always be much less than the maximum speed of which a given plane is capable. Fuel consumption increases especially at supersonic speeds. A contemporary jet aircraft flying at supersonic speeds consumes its total fuel supply in a very short time. Long distance flights at high speeds (Mach 2-3) are impossible at the present time.

Only by the utilization of nuclear fuel can the problem of long flight range at supersonic speeds be solved. It should be noted that in one gram of uranium-235 there is approximately the same amount of energy as in 2 tons of kerosene which is used as jet engine fuel. This means that nuclear fuel consumption would be 2 million times smaller than the consumption of kerosene. For example, an aircraft weighing 100-150 tons in a round-the-world flight at a speed of 2,000 km/hr would consume only 500 grams of uranium-235.

Contemporary aviation is one of the largest consumers of petroleum distillation products. If only a fraction of the total aircraft could be converted to nuclear fuel, then petroleum in greater quantities than is possible at the present time could be used as a raw material in the chemical industry. It will not be necessary to transport large amounts of kerosene and gasoline to airfields which are located far from petroleum resources and distillation plants. Aircraft will be supplied with nuclear fuel right at bases which are used for preventive maintenance work on engines.

This booklet discusses the possible ways of building an atomic aircraft engine and the characteristics in which an atomic aircraft will differ from a conventional one.

The Basis of Nuclear Power

At the present time, for the purposes of obtaining power the fission of nuclei of isotopes of some heavy elements is utilized. These isotopes are uranium-235, which is found in natural uranium in the amount of 0.7 percent, and also artifically produced uranium-233 and plutonium-239.

Let us examine how the fission reaction proceeds in uranium-235. In uranium there are always free or so-called "wandering" neutrons. Such a neutron, when it impacts a nucleus of uranium-235, imparts energy to it. The nucleus becomes excited and unstable. In most cases, the nucleus fractures, resulting in two fission fragments which fly apart. In addition, at the moment of fracture 2-3 new neutrons are released, called secondary neutrons. If the piece of uranium is of sufficient size, each of the secondary neutrons can impact another uranium nucleus and cause new fission, as a result of which still more free neutrons are emitted; that is, under controlled conditions the fission reaction can be self-sustained. Reactions of this type are called chain reactions.

The fission fragments of the uranium nuclei are excited, unstable atomic nuclei of other elements. Their transition to a stable condition is effected by emission of charged particles--electrons and positrons--electromagnetic waves, gamma rays, and to a lesser extent by emission of so-called delayed neutrons. The largest amount of energy during the fission reaction, more than 80 percent, is released in the form of kinetic energy of the fission fragments of the uranium nuclei. The speed of these fragments immediately after fracture is equal to 10,000-15,000 km/sec. The fission fragments impart energy to the surrounding atoms, increasing the speed of their random movement, i.e., the fragments heat the surrounding matter. In this way, nuclear energy is released in the form of thermal energy, which can be most practically used in heat engines. Therefore, all contemporary atomic power installations utilize heat engines--steam or gas turbines.

The heat source in all contemporary atomic power installations is the nuclear reactor--the device in which the self-sustained, controlled nuclear reaction proceeds. Figure 1 shows a schematic arrangement of one nuclear reactor type.

The nuclear fuel is uranium utilized in the form of bars, so-called fuel elements. To prevent corrosion the uranium bars are enclosed in protective cladding. Each bar is held in place in the reactor with a special apparatus. The attachment should be firm and at the same time it should allow for sufficient clearance for deformation caused by a change in temperature in the bar.

It is not possible to achieve a nuclear chain reaction in a piece of natural uranium. The reason for this can be explained as follows. Natural uranium is composed of two isotopes, uranium-238 and uranium-235. In the process of a nuclear fission reaction, fast neutrons are released which have a speed of 10,000-20,000 km/sec. The nuclei of uranium-238 can be split only under action of fast neutrons. The neutrons after collisions with the nuclei of structural materials or with the nuclei of uranium cannot cause fission of the uranium-238 but instead are absorbed by it.

The nuclei of uranium-235 can be split by either fast or slow neutrons; because of this, neutrons are captured more intensively by uranium-235 than by uranium-238. But when bars of natural uranium are enclosed in a moderating medium, then a chain reaction is possible. In this case, most of the fast neutrons which are released during the fission of the uranium nuclei fly out from the fuel element into the moderating medium. Upon colliding with nuclei of the moderating medium, the neutrons give up energy and their speed decreases. The greatest part of the neutrons which have been slowed down return to the fuel elements, and here they are captured primarily by the uranium-235 nuclei causing their fission. The moderator also increases the probability of neutron capture by the uranium-235 nuclei and decreases their harmful absorption by the uranium-238 nuclei. Thus, a self-sustaining nuclear reaction with natural uranium is achieved.

The utilization of a moderator material in the reactor is found to be of value when high-efficiency nuclear fuel is employed, e.g., uranium enriched in the isotope 235. In such a case, since the neutron speed is decreased and the capture probability is increased, the charge of nuclear fuel in the reactor can be decreased. Thus, by employing a moderator in the reactor, the nuclear fuel requirement is decreased.

Light elements which have a small absorption cross-section are employed as moderators. Such elements are heavy hydrogen, ordinary hydrogen, carbon and beryllium. These elements can be utilized in the pure state, e.g., carbon in the form of graphite, or in the form of a compound with other elements. Such a compound as heavy water is a good moderating material.

That part of the reactor where the uranium fuel is located and the fission reaction takes place is called the core. Normally around the core a neutron reflector is placed. The purpose of the reflector is to return most of the escaping neutrons to the core. The use of a reflector also decreases the amount of nuclear fuel requirements for the operation of the reactor. The materials used for the neutron reflector are the same as for the moderator.

The heat created in the reactor is carried off by a heat transfer medium. Ordinary water under high pressure can serve as a heat transfer material; liquid metals--sodium, potassium, lead, bismuth and others--and gases--helium, nitrogen, carbon dioxide--can also serve as coolants. Water is used in only low-temperature reactors, since even at 200 atmospheres pressure its boiling point is 365°C. Therefore, water as a heat transfer medium requires the utilization of steam turbines.

If in an atomic power plant a gas turbine is used, then liquid metal or gas should be employed as the heat transfer medium. Each of these has its advantages and disadvantages. For example, the use of sodium results in a reactor with the smallest heat transfer surface without increase of pressure in the system. But at high temperatures the structural metals decompose and this can cause a breakdown. Moreover, sodium becomes radioactive when exposed

to neutron radiation. Helium does not become radioactive, nor does it decompose metals; but in order to decrease the heat transfer surface, it is necessary to increase the pressure in the system, and as a result of this the reactor structural materials and the wall thickness of the piping system must be increased. Besides this, the power consumption for the circulation of gaseous heat transfer media is much greater than the power consumption for circulating liquid metal. In each design of an atomic power plant the most favorable heat transfer material is selected. The maximum temperature attained by the heat transfer material in the reactor may be limited not only by the characteristics of the heat transfer medium itself, but also by the material characteristics of the reactor and the strength of the piping system which decreases with increasing temperature.

Let us look at some of the characteristics of heat transfer from the reactor. In order that the heat can be transferred from the fuel elements to the heat transfer medium, the temperature of the fuel elements should be higher than the maximum temperature attained by the heat transfer medium when it reaches the exit of the reactor. When employing liquid metal as the coolant, this temperature differential, called the temperature gradient, is only of the order of several degrees. When the heat transfer medium is a gas, then the temperature gradient at the exit of the reactor is equal to some tens of degrees. Because heat is generated in the whole volume of the fuel element and is carried away only at the surface, then the temperature within the fuel element is higher than at its surface. Depending on the thermal conductivity of the fuel element material and the amount of heat emitted in one second in a unit volume, the temperature differential within and on the surface of the fuel element may be more or less significant. The maximum temperature of the heat transfer medium will determine either the temperature inside the fuel element, or the temperature differential within and on the surface of the fuel element. If the temperature inside the fuel element has a specific limit, e.g., the melting point of the material, then the fuel element can be destroyed. If the temperature differential is exceedingly large, then the inner layers of the fuel element, as a consequence of higher thermal deformation, will tear apart, and as a result destruction of the fuel element will follow. The design engineer's problem is to select proper materials and to find such fuel elements which will not decompose and which will ensure the heating of the heat transfer material to the required temperature.

Let us examine the power controls of the type of reactor under discussion. The amount of heat emitted in one second in the reactor is called the thermal power of the reactor. The amount of heat that is emitted during the fission of the nuclear fuel, i.e., the thermal power of the reactor, is proportional to the number of fissions of nuclei in one second. The latter, at a given concentration of nuclear fuel, is determined by the quantity of neutrons in the reactor. By varying the quantity of neutrons, it is possible to vary the thermal power of the reactor. If during the fission of each fuel nucleus from 2-3 secondary neutrons are released, and if only one will cause a fission of the next nucleus and the rest escape, then after some time the number of fissions will not change. For a given shape and size of reactor, such a condition is achieved at a strictly determined so-called critical amount of nuclear fuel and is called the critical condition of the reactor. A reactor in critical condition develops constant thermal power, i.e., the critical work regime of the reactor is stationary. In the case where the quantity of nuclear fuel in the reactor exceeds criticality, the reactor is in a supercritical condition. The number of nuclei fissions

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increase with time in this case, and the thermal power continuously increases. The condition of the reactor in which the number of nuclei fissions decrease with time and as a consequence the thermal power falls off is called a subcritical condition. This happens when the amount of nuclear fuel in the reactor is less than critical.

If a reactor is loaded with the quantity of fuel required for criticality, then with the consumption of a certain amount of the fuel the reactor will become subcritical and the nuclear chain reaction will stop. To prevent this, an extra charge of nuclear fuel is initially added to maintain the chain reaction. In order to compensate for the surplus nuclear fuel at the start of reactor operation, control rods are employed. These control rods are made of materials which intensively absorb thermal neutrons. By changing the position of the control rods in the reactor, we can regulate the number of neutrons absorbed by them: if the control rods are moved further inside the reactor, they will absorb more neutrons, and, on the other hand, if they are moved more towards the outside, they will absorb less neutrons. A reactor is so designed that the control rods are partially out at the critical condition. With the consumption of a quantity of nuclear fuel, the control rods are moved still further outside. In this way the critical condition of the reactor is maintained.

In order to visualize how the reactor is controlled, let us look at what happens to the neutrons when the reactor is in critical condition. For better demonstration, let us use some numerical values and assume the fuel to be natural uranium. Let us assume that one hundred nuclei of uranium-235 are fissioned under the action of thermal neutrons. On the average they will release 250 fast secondary neutrons. What happens to them is shown on the following schematic:

100 nuclei of uranium-235 are fissioned under action of 100 captured thermal neutrons.
↓
250 fast neutrons are released in the fission process.
→ 20 fast neutrons escape from the reactor without slowing down.
→ 60 neutrons are absorbed by uranium-238 in the moderating process.
↓
170 neutrons are slowed down.
→ 10 thermal neutrons escape from the reactor.
→ 20 thermal neutrons are absorbed by the moderator, heat transfer medium, structural materials, impurities, and uranium-238.
→ 20 thermal neutrons are absorbed by the control rods.
↓
120 thermal neutrons are captured by the uranium-235 nuclei.
→ 20 thermal neutrons fail to split the uranium-235 nuclei (excited nuclei in such cases become stable by emitting gamma rays).
↓
100 thermal neutrons cause fission of the uranium-235 nuclei and the process repeats itself as above.

If the control rods are partially removed from the reactor, then the absorption of thermal neutrons by them decreases. A larger number of uranium-235 nuclei will be captured and therefore more than 100 nuclei for each 100 original nuclei will undergo fission in the above cycle. In this manner, the number of fissions will increase from one cycle to another and the thermal power of the reactor will increase with time.

At the moment when the desired power is reached, the control rods are moved in to such an extent that the number of fissions is constant, i.e., the reactor will operate at the critical condition. The position of the control rods at the new stationary condition after the power has been increased may not coincide with their position at the original stationary condition. This is explained by the changes in temperature in the reactor when the power was increased; as a consequence of this, the numerical relationship between the escape and capture of neutrons by the moderator, by the uranium-235, and so on is changed. In order to obtain a critical condition, it is necessary to change the neutron capture ratio of the control rods, i.e., as a rule, the position of the control rods should be changed. The temperature change is especially noticeable when the reactor power change is accompanied by a temperature change in the heat transfer medium.

In order to reduce the power level the reactor is changed to a subcritical condition by moving in the control rods. When the power is reduced to the desired level, the control rods are moved out again in such a way that the reactor will operate again at the critical condition.

One of the important moments in the operation of a nuclear reactor is at start-up. There is a difference between an original start-up and a start-up after a reactor has already been in operation. The original start-up is accomplished by utilizing an outside neutron source. In subsequent start-ups fission fragments which were created during the preceding operation of the reactor serve as a neutron source.

Reactors designed for transportation power plants have tremendous power in small dimensions. This is accomplished by increasing the density of the neutron flux in the reactor, i.e., the number of neutrons passing through 1 cm^2 in one second. The greater the neutron flux density, the greater is the thermal power of the reactor.

At a high neutron flux density a "poisoning" effect of the reactor takes place, caused by xenon-135, one of the products of uranium-235 fission. This effect is such that when the reactor is shut down after a long period of operation it can be started again by moving out the control rods, but only after some tens of minutes. If at this time the reactor won't start, then it won't start even for some hours subsequent to this, and can only be started again in 24-48 hours. This characteristic can be explained in the following way: xenon-135 absorbs thermal neutrons very intensively and therefore even at very small concentrations prevents the initiation of the self-sustained nuclear chain reaction in uranium-235.

Only 5 percent of the xenon-135 is formed as an indirect product of uranium-235 fission, and 95 percent of the xenon is formed through radioactive transmutation of another product or uranium fission, tellurium-135. Tellurium-135 changes very quickly into iodine-135. Iodine-135 has a half-life of 6.7 hours and is changed into xenon-135. The latter is also unstable (half-life of 9.2 hours) and decays into the quite stable cesium-135. In the operational process of the reactor, xenon-135 changes into xenon-136 under the action of the neutron flux. Of all these isotopes only xenon-135 strongly absorbs thermal neutrons.

Xenon-135 concentration in a reactor is determined by: (1) the speed with which it forms from iodine-135 on the one hand, and (2) the speed with which it changes into cesium-135 and xenon-136 on the other. At the start-up of reactor operation when there is only a small quantity of xenon-135 it changes into cesium-135 and xenon-136 at a lesser rate than the rate of formation from iodine-135. The xenon-135 concentration increases for some time. This makes it necessary to move out the control rods gradually to compensate for the increase of neutron absorption by xenon-135. After the reactor is continuously operated for several hours, the concentration of xenon-135 reaches such an amount that the transmutation rate of xenon-135 becomes equal to the rate of its formation, and at this moment its concentration at the reactor steady state is constant. The possibility of compensating for the "poisoning" effect of xenon-135 by moving out the control rods makes it necessary to have an excess of nuclear fuel for "poisoning". The necessity to have an excess of nuclear fuel in the reactor for the "poisoning" effect, burn-up, and the temperature effect makes it clear that the originally-determined loading of nuclear fuel significantly increases.

After a reactor is shut down, the formation of xenon-135 continues initially almost at the same rate, because a quantity of iodine-135 has already been formed in the reactor. The decrease in xenon-135 proceeds at a considerably lesser rate, since it changes only into cesium-135. The transmutation of xenon-135 into xenon-136 after the reactor is shut down practically ceases, since the neutron flux density rapidly falls off. Therefore, the equilibrium between the rate of formation and rate of loss of xenon-135 is disturbed and its concentration begins to increase. Within a considerably short period of time after shutdown of the reactor, decreasing to a half hour if the reactor was operated at a high density neutron flux, the xenon-135 concentration reaches such an amount that even complete removal of the control rods cannot compensate for its neutron absorption. At this moment start-up of the reactor is impossible. After some time the xenon-135 concentration reaches a maximum and then starts to decline. After 30-40 hours of shutdown the reactor can be started again.

Analogously, but with much less pronounced effects, a nuclear reactor is "poisoned" with another uranium fission product--samarium-149.

The "poisoning" effect of a reactor makes it difficult indeed to exploit any transportation atomic power plant. It is, however, characteristic only for those types of reactors in which uranium-235 fission is brought about by thermal neutrons. The limit of neutron velocity reduction in a reactor is the velocity of random thermal movement which is related to the reactor temperature. A reactor in which neutron velocity is slowed down to this limit by the moderator is called a thermal neutron reactor. The nuclear fuel in such a reactor may be evenly dispersed in the moderating medium, forming a homogeneous mixture, or it may be placed in the form of separate blocks, for instance, bars surrounded by pure moderating medium. In the first case, the reactor is called homogeneous, in the second, heterogeneous.

There are reactors in which the moderator is absent. In such reactors the fissioning of the nuclear fuel is accomplished by the action of fast neutrons. The heat transfer medium is usually a liquid metal. A fast neutron reactor may be either homogeneous (e.g., when uranium-235 is dissolved in bismuth) or heterogeneous (e.g., when the uranium fuel elements are surrounded a sodium heat transfer medium). Because the possibility of capture of fast neutrons by the fuel nucleus is small, in fast neutron reactors, therefore, it is necessary to use highly effective nuclear fuel, e.g., enriched uranium containing several tens of percent

of the 235 isotope. The quantity of nuclear fuel required by a fast neutron reactor is many times larger than that required by a thermal neutron reactor. But the advantages of a fast neutron reactor should be considered: smaller dimensions and weight and absence of the "poisoning" effect because xenon-135 and samarium-149 do not significantly absorb fast neutrons. Iron is very often used as a reflector of fast neutrons.

But there is a difficulty with fast neutron reactors because control rods cannot be employed in the reactor core, since there are no materials which strongly absorb fast neutrons. Therefore, the density of the neutron flux is regulated by changing the rate of escape of the neutrons from the reactor. Control of the escape of neutrons is accomplished by moving the neutron reflector. Usually there are control rods in the neutron reflector made of the same material as the reflector. When the control rods are moved into the reflector, it has maximum reflecting capability, and when they are moved out, it has a minimum capability. When the reactor is in a critical condition, the control rods are in an intermediate position. In order to change the reactor to a supercritical condition, it is necessary to decrease the escape of neutrons, i.e., to move the control rods in. And to change the reactor to a subcritical condition, one must move the control rods out of the reflector.

There are reactors of an intermediate type between those reactors operating on fast neutrons and on thermal neutrons. In such a reactor there is a moderator which reduces the velocity of fast neutrons, yet the velocity remains higher than the speed of thermal movement. The objective of such a reactor is to exploit the advantages of both the thermal neutron reactor and the fast neutron reactor.

In order to achieve safety in operations in case the main system of control in the reactor fails, there is an emergency system which can be used to shut down the reactor when there is deviation in the normal operating regime. The reasons for such deviations are: exceeding the permissible reactor power level or temperature limit, loss of the heat transfer medium, fall in pressure in the coolant system, and so on. For emergency shutdown of a thermal neutron reactor the emergency control rods which are employed strongly absorb thermal neutrons. In normal operations these control rods are removed completely from the reactor. In an emergency they immediately fall into the reactor and the nuclear chain reaction stops.

An emergency control system for a fast neutron reactor is achieved by removal of part of the neutron reflector. Usually the lower section of the reflector is attached to special hinges. In case of an emergency the hinges unlatch and the section falls under its own weight. This permits the escape of the neutrons and the chain reaction stops.

A reactor in operation and for some time after operation is a powerful source of beta particles, neutrons and gamma rays. This radiation is harmful to the environment around the reactor and to living organisms. The beta radiation has a weak penetrating capability and is completely stopped by the structure materials of the reactor. In order to stop the neutrons and gamma rays, special precautions are taken: the reactor is surrounded with a thick shield which completely stops the radiation. The materials chosen for the shield must consist of substances which have the ability to absorb neutrons and gamma rays. Because

fast neutrons have a high penetration capability, the best way to stop them is to first slow them down, then to absorb them. The best material for this purpose is boron and ordinary water. Gamma rays are best stopped by heavy elements--lead and iron. The shield may consist of several layers, each of which is designed for stopping neutrons or gamma rays. Sometimes the shield is made of homogeneous material, e.g., concrete. The overall thickness of protective shields may reach a few meters.

We clearly laid out the basic principles of the construction of power reactors. Let us now dwell on some of the features of a reactor designed for operation in an aviation power plant.

It is known that the reactor of the first Soviet electric power plant has a thermal power capacity of 30,000 kw. The reactor core has a cylindrical shape, its diameter is 1.5 meters, and its height 1.7 meters. The core is surrounded by a neutron reflector of graphite with a thickness of 0.7 meter and the shield overall thickness is about 4 meters. The largest contemporary heavy aircraft have a fuselage diameter of about 3-4 meters. A reactor designed for an aviation power plant should have dimensions which would enable it to fit in such a fuselage. In order to fly a heavy aircraft at a speed of 1,000 km/hr at an altitude of 11 km, a reactor power is required which is approximately 10 times that of the reactor of the first atomic power plant. And if the aircraft should increase its speed to 2,100 km/hr, approximately 2 times the speed of sound at that altitude, then the reactor power should be increased 3-4 times. With a decrease in flight altitude the reactor power required to attain a given speed increases still more.

In order to operate aircraft engines it is necessary that the fuel surface temperature of a reactor reach 900-1,000°C. This requirement makes the design of an aircraft reactor difficult and necessitates the utilization of special materials. For instance, in the selection of the nuclear fuel, uranium cannot be used since its crystal lattice at temperatures of 660°C and 760°C modifies its structure, so that its volume and mechanical properties are changed. Repeated heating of uranium above these temperatures causes disintegration of the protective cladding and destruction of the fuel elements. In the selection of suitable fuel for high-temperature reactors it is expedient to use uranium oxide or uranium carbide, and the cladding of the fuel elements is frequently not favorable with respect to their nuclear properties: special steels, chromium-nickel alloys, and so on. The highest temperatures may be attained in reactors in which both the nuclear fuel and the moderator is in the form of ceramics. Such a reactor could operate at temperatures close to 2,000°C. But it has disadvantages with respect to the low density and brittleness of the ceramics.

The high thermal stresses in an aircraft reactor, caused by a tremendous power concentration in small dimensions and the high operating temperatures, will naturally decrease its service time, or so-called operation life. It is to be understood that the operation life of an aircraft reactor will be equal to the operation life of an aircraft engine, i.e., it will operate for about 100-200 hours. One should not think that this is not enough. At a flight speed of 2,000 km/hr an aircraft with a reactor having an operation life of 200 hours can travel a distance of 400,000 kilometers, i.e., it can circle the earth 10 times. In comparison it should be noted that contemporary long range aircraft with 200-hour operation life engines can travel only about 150,000 kilometers and at a considerably lesser speed.

The operational conditions of a reactor in an aircraft are much more complicated than those of a reactor in an electric power plant. During flight an aircraft reactor assumes different positions in space. Thus, while gaining altitude the front of the aircraft will be tilted up, and during decent - down. When undergoing a change in speed or direction, inertial forces are present. The reactor during such flight will operate in conditions of joggling and bumping. All this increases the strength requirements of the reactor. In this way, the application of atomic energy for the operation of aircraft engines meets with great difficulties. But the contemporary level of development of science and technology gives promise that such difficulties will be solved and that a reliable, uncomplicated aircraft reactor will be built.

Atomic Aircraft Engines

Let us analyze the possibilities of using nuclear energy in aircraft power plants. Nuclear energy in contemporary reactors is transformed into thermal energy. Therefore, atomic engines may be thermal engines, similar to ordinary aircraft engines.

At the present time there are two types of aircraft engines widely used: turbojets and turboprops. The turbojet engine operates on the following principle: atmospheric air is compressed by a compressor and is directed into a combustion chamber; the fuel is injected into this same chamber (usually kerosene) which after combustion heats the air to temperatures of 800-900°C. The combustion products turn the turbine, which is necessary for the rotation of the compressor, and the gases are ejected through the jet nozzle into the atmosphere. Since the hot gases are ejected out of the engine at a higher velocity than the air enters, a propulsive thrust is created.

Figure 2 shows a schematic drawing of an airplane with two atomic turbojet engines operating on this principle. Air compressed in the compressor is directed through special ducts to the reactor, which replaces the combustion chamber. The air which is heated in the reactor is returned to the turbines. Passing through the turbines, the air is ejected out through the jet nozzle at high speed.

Aircraft with atomic engines will fly at high supersonic speeds. At such speeds a shock wave forms in front of the engines, which sharply decreases the propulsive power of the engine. Inlet cones which are shown on the schematic are placed in front of the engine to decrease the intensity of the shock wave and in this way to decrease the loss of propulsive thrust.

The supply of air to the reactor through the tremendous ducts makes the arrangement of atomic power plants on an aircraft inescapably difficult. In order to heat the air in the reactor a large heat exchange surface area is required: about 800-1,000 square meters for an aircraft with a flying weight of 100-120 tons. This forces the reactor to large dimensions, to an increase in weight, and of course an increase in aircraft weight and a decrease in its flying speed.

The heating of the air in an atomic turbojet engine may be accomplished in a heat exchanger with the aid of a metallic heat transfer agent (Fig. 3). The heat transfer surface required to heat the liquid metal is many times smaller than the surface required to heat the air; therefore, the reactor can be smaller and lighter. But the weight of the heat exchanger and the heat transfer medium

add to the weight of the engine. Whether an engine with the air heated in the reactor or with the air heated in a heat exchanger is more advantageous depends on the flying weight of the aircraft and its designed flight speed. The latter type is especially favorable in multiengine aircraft, since the operation of more than one engine is possible from a single reactor.

Part of the energy of the heated air is lost in the turbine; therefore, the air temperature behind the turbine is 150-200°C lower than in front of the turbine. The air exit speed from the jet nozzle, and accordingly the propulsive thrust of the engine depends on the air temperature in front of the nozzle. The higher the air temperature in front of the nozzle, the higher is the propulsive thrust; therefore, it is advantageous to heat the air additionally behind the turbine. The simplest way to do this is to place an additional heat exchanger between the turbine and the jet nozzle. The heat transfer medium from the reactor first passes into the additional heat exchanger. There it gives up some of its energy to the air flowing into the nozzle. Then the heat transfer medium is returned to the original heat exchanger where it heats the air directed towards the turbine. In this way the air temperature in front of the turbine is lower than when the heat transfer medium flows directly into the main heat exchanger located in front of the turbine. This lowers the coefficient of useful turbine action and increases the nuclear fuel consumption. But since the consumption of nuclear fuel is very small, lowering the turbine efficiency is made up by an increase in propulsive thrust. Another way to increase the air temperature in front of the jet nozzle is to use a steam or gas turbine instead of a compressor. This turbine will not use the thermal energy from the air heat exchanger; therefore, the velocity of the air exhaust from the nozzle and consequently the propulsive thrust will increase.

Figure 4 shows a schematic of an aircraft having two atomic engines with the air compressor being driven by a helium turbine. Helium which is heated in the reactor is directed to the turbines, then flows into the heat exchanger. In the heat exchanger the helium is cooled. The air passing through the engine is heated by the heat given up by the helium. A helium compressor compresses the helium from the heat exchanger and returns it to the reactor. In each engine there is a power loss, in addition to the power used by the helium compressor, which is used for the rotation of the air compressor. The power ratio is approximately as follows: if the power of the helium turbine is equal to 150,000 hp, then 100,000 hp is used by the helium compressor and 50,000 hp by the air compressor. It is clear that the efficiency of such an arrangement is not very high.

The power requirements are less when the air compressor is operated by a mercury vapor turbine. Mercury, which is changed into vapor in the reactor, then is directed to the turbine which is connected to the air compressor by means of a shaft. The vapor flows from the turbine to the condenser-heat exchanger. Upon condensing into liquid mercury, the vapor heats the air. Because of the low temperature of condensation of mercury, even at the increased pressure in the condenser, the propulsive thrust, given equal dimensions, will be somewhat less than in the case of a gas, e.g., helium, turbine. However, the nuclear fuel requirements will be lower because instead of the 150,000 hp turbine a turbine of only 55,000 hp will be required, of which 50,000 hp as before will be used by the air compressor and only 5,000 hp will be used by the mercury pump. If the coefficient of useful action of the steam turbine is

the same as for the gas turbine, then the decrease in steam turbine power requirements will also result in a decrease in reactor power, if the engine propulsive thrust is the same. But as a rule the coefficient of useful action of a gas turbine is much greater than for a steam turbine. Therefore, the economic gain due to the decrease of steam turbine power is lost to a significant degree, and the resulting reactor power for both engines is about the same. When comparing the drive of an air compressor by gas and mercury turbines, it should be kept in mind that it is much more complicated to build a reliable reactor where mercury is changed into vapor than it is to build a gas-cooled reactor.

There is one more way of increasing the air temperature in front of the nozzle which should be noted. The idea of this method is to pass only a part of the air of the atomic turbojet engine through the turbine. By doing this, the thermal energy of the air flowing through the turbine will be considerably lowered, and it will not be able to play an effective role in the creation of propulsive thrust. However, that part of the air which enters the exhaust nozzle after by-passing the turbine will have the same temperature to which the air was heated in the reactor or the heat exchanger. Therefore, the velocity of the exhaust from the jet nozzle will be greater than in the case where all the air flows through the turbine. In consequence, the propulsive thrust will increase.

A contemporary aircraft turboprop engine differs from a turbojet engine only in that most of the propulsive thrust is obtained from the propellers, and only 10-15 percent of the propulsive thrust is created by the reaction of the exhaust gases. The propellers are caused to rotate either by the use of reduction gear associated with the same turbine which rotates the air compressor or by means of a special turbine. Usually two coaxial propellers rotating in the opposite direction are utilized. In this way the "torque" of the air stream behind the propellers is completely obviated and the engine efficiency increases. An atomic turboprop engine differs from an atomic turbojet engine in exactly the same way (see Fig. 5), i.e., by the presence of propellers and reduction gear. Since the turbine of such an engine should be much more powerful than the turbine of a turbojet engine, it should be multistage.

In the atomic turboprop engine it is also possible to utilize steam or gas turbines. In this case an air compressor is required only to force air through the condenser-heat exchanger. Figure 5 shows the schematic construction of an atomic turboprop engine with a mercury turbine.

It is possible to install on an aircraft which has steam turbine atomic turboprop engines or in general for all engines a "boiling water" type of water reactor (Fig. 6). This type of reactor consists of a thick-walled pressure vessel containing ordinary water into which is placed a grid of enriched uranium rods encased in zirconium cladding. Water as the moderator causes the nuclear reaction to proceed. The heat which is evolved heats the water and converts it into steam. Either in the upper part of the reactor or above the reactor a steam separator is located, which separates small water particles from the steam and returns them to the reactor. The steam which is formed is ducted through the piping system to the engines' steam turbines. The steam after being used passes into a condenser, is cooled by a stream of air, and is condensed to water which is again pumped into the reactor. The turbine, by means of a reduction gear, rotates the propellers which create propulsive thrust.

The application of atomic energy in other kinds of aircraft engines is also possible. Figure 7 shows a general view and schematic of an airplane having two atomic ramjet engines located above the fuselage and one atomic rocket engine located in the fuselage. The ramjet engine is essentially a "flying reactor" to which an inlet diffuser which directs a supply of air to the reactor is attached at the front, and behind it there is a jet nozzle through which hot air is discharged at a greater velocity than the velocity of the airplane. Propulsive thrust is created because of the difference between the inlet and exhaust velocities of the air. The fault of a ramjet engine, either atomic or ordinary, is that it can increase its propulsive thrust only at high speeds; therefore, an aircraft must have some other engine besides the ramjet engine in order to take off and accelerate, e.g., an atomic rocket engine (see Fig. 7).

The propulsive thrust from a nuclear rocket engine is created by the exhaust of hot gases at high velocity. The gases are formed in the reactor from some fluid substance which is stored on the airplane and which is supplied to the reactor by pumps. Such a substance could be, for example, liquid hydrogen. The higher the temperature to which the gases are heated in the reactor, the higher is their exhaust velocity from the nozzle, and the greater is the propulsive thrust. For this reason, the gases should be heated to the highest possible temperatures.

This requirement for heating the discharge gases to the highest possible temperatures applies not only to the rocket engine but also to all other types of aircraft engines. Let us compare atomic engines with ordinary engines operating on chemical fuel from this point of view. When the temperature of the combustion products in a liquid fuel engine reaches 2,500-3,000°C, the wall of the combustion chamber is maintained below 1,000°C. If we should take an atomic engine where the heating of the air or some other substance is accomplished by heat exchange at the heat-exchange surface of the reactor, then the picture is different. The temperature of the heated gas will be 100-150°C lower than the temperature of the reactor's heat-exchange surface; the latter is limited by the requirements of stability and operational reliability. In this way, the heating of the air by means of the heat-exchange principle is the major deficiency of atomic engines when compared to ordinary engines, in that it does not permit the achievement of the efficiency attained by the fuel energy obtained in contemporary aircraft engines.

However, engineers are not satisfied with the accomplished results and work ceaselessly on the creation of new designs of more advanced atomic engines. Thus, for example, it has been suggested that the air be additionally heated outside the reactor through the combustion of ordinary chemical fuel, e.g., kerosene or gasoline. The application of this engine may appear to be expedient, but an aircraft with such an engine, just as with any other engine which works on chemical fuel, will have a limited flight range not very much greater than the flight range of contemporary heavy aircraft. It seems that it might be possible to heat the air in ramjet or turbojet atomic engines by mixing it with gaseous, liquid or powdered nuclear fuel, which in the neutron flux in the reactor core would undergo fission and liberate heat. The heat in this case would be liberated in the entire volume of the air, thus eliminating the necessity to heat the air by a heat-exchange surface.

If an atomic ramjet engine should operate on gaseous nuclear fuel (see Fig. 7 in the upper right corner), then the air which is mixed with this gaseous fuel is directed into the reactor cavity. There the nuclear reaction takes place and as a result the air is heated. Then the air passes on out through the nozzle. The reactor in this engine is a powerful source of neutrons. But during the nuclear reaction neutrons are liberated, and naturally this is accompanied by the liberation of heat. This heat must be removed from the reactor and can be used for the operation of the turbine on any other engine installed on the aircraft. The possibilities of using this type engine depends on the quantity of gaseous nuclear fuel that is consumed. Calculations show that at neutron flux densities in the reactor which are possible at the present time, the probability of neutron collision with the gaseous nuclear fuel nuclei is very small. In order to achieve the required heating of the air in the engine, the consumption of gaseous nuclear fuel would be very large; therefore, it is not practicable to build such an engine.

The schemes for aircraft atomic engines which we have described, of course, do not cover all variations of possible forms and applications of atomic energy in aviation. However, they show visual representations of possible designs of atomic aircraft engines.

Design Principles of Aircraft with Atomic Engines

The design principles of atomic aircraft are determined by the existence of the reactor, whose operation is accompanied by the intensive radiation of gamma rays and neutrons, and by the necessity of shielding against this radiation. The intensity of the radiation of a reactor is approximately inversely proportional to the square of the distance from it. The further the reactor is located from a person, the less will be the protection required. Beginning with this relationship, the basic principle of reactor location on an aircraft is that it should be at the furtherest possible distance from the passenger cabin (crew compartment). The safe distance from a reactor without protective shielding is 1-1.5 kilometers. Since an aircraft cannot have such a length, a protective shield is necessary.

Stationary reactors are surrounded on all sides with a concrete shield of a total thickness of more than two meters. A steel shield or a shield of some heavy material such as lead can be thinner, but its weight will be quite great. Calculations show that the weight of a shield from known, existent materials is so great that an aircraft will not be able to leave the ground. Therefore, besides searching for new shielding materials, the possibility of employing a so-called "shadow" shield is considered instead of a solid unit shield. This is a shield located between the reactor and the crew compartment. The crew compartment would be, in this case, in the shadow of the shield and would not be subjected to direct reactor radiation. In order to protect the crew compartment from the radiation scattered from the air and from construction materials, it will be enclosed in a quite thin protective shield. Such a shield could be, for instance, a steel shell around the crew compartment. Besides serving to protect against the scattered radiation, this shell can serve as an integral part of the frame, to which other parts of the airplane could be attached. The weight of the "shadow" shield is favorable.

It is in general possible to build such an airplane, the atomic engines of which with the reactor and protective shield would not weigh more than the weight of ordinary engines with the necessary fuel for them. The minimum flying weight of an aircraft for which these conditions hold would probably be between 90-100 tons. The payload would be from 5-10 tons, i.e., the aircraft would be able to transport from 50-100 persons.

With an increase in the aircraft weight, the protective shield weight decreases. This is able to be explained as follows: if the aircraft weight should be doubled, then the engine power should also be approximately doubled and the radiation intensity almost doubles also. In order to compensate for this increase in radiation intensity, the thickness of the protective shield will increase a few centimeters. The protective shield weight will be increased by only a few percent. Therefore, the proportion of the shield weight with respect to the total aircraft weight will considerably decrease.

For these reasons, the design of aircraft with a flying weight greater than 100 tons is much easier, and it might present more rational solutions to problems since with the increase of aircraft weight there can be an increase of payload capacity as well. The application of the "shadow" protective shield should be considered a necessity which creates certain unfavorable conditions but which at the present time is probably the only possibility.

Contemporary heavy jet aircraft have a flying weight up to 150 tons and greater. About half of this weight consists of fuel for the engines. In flight, fuel is consumed and the aircraft weight decreases several tons per hour. An aircraft with a weight of 100 tons at take-off weighs only about 50 tons at landing.

The picture is completely different for an aircraft having atomic engines. The small amount of nuclear fuel consumption does not change the aircraft weight in flight. The take-off weight of an atomic aircraft is practically the same as the landing weight. This leads to some peculiarities in atomic aircraft not found in ordinary ones. Of great importance is the landing speed of an aircraft--the speed with which the aircraft touches the earth on first contact. The heavier the aircraft, the higher is its landing speed, provided however that the wing area is the same. The landing speed of contemporary aircraft is 2-3 times greater than the speed of an express train. In an atomic aircraft where the landing weight is equal to the take-off weight, the landing speed will be 4-5 times greater. An increase in the landing speed will require stronger landing gear, which in turn increases the aircraft weight. The landing run on the runway will increase also, and this means that the airfields for atomic aircraft will have to be larger than for contemporary aircraft. Present airfields will have to be enlarged.

The landing itself at high speeds is not so simple. Everyone knows how unsure an automobile is at high speeds. For high speed operation one has to get used to it. And to control an aircraft landing at a speed 4-5 times that of an express train is much more complicated and dangerous. Thus, the problem of landing an atomic aircraft is of great significance.

In order to decrease the landing speed and run, many possibilities can be applied to contemporary aircraft. For example, the landing speed can be decreased by increasing the wing area. This is done by moving out special "flaps". In order to decrease the length of the run, brakes are applied. However, all of these possibilities are applied to contemporary aircraft and in the transition to atomic aircraft new means have to be found to achieve safe landings on small airfields.

The question of vertical take-off and vertical landing presents a strong possibility. In the last few years in some countries, experiments have been carried out aimed at building such aircraft that could take off vertically without an accelerating run. The principle of vertical take-off consists of the following: an airplane is placed in a vertical position before take-off. The engine, usually a turboprop, creates a propulsive thrust which is greater than the aircraft weight by about 30-40 percent, and the airplane begins to rise vertically. As it begins to gain altitude and speed, the pilot puts it into a horizontal position, continuing the flight. Before the landing, the pilot decreases the speed, the airplane "suspends", and then gradually lands on the "tail assembly". After landing, the airplane assumes a more stable horizontal position.

At the present time the vertical take-off of a heavy aircraft is unthinkable, because it is practically impossible to build such powerful engines that could create a propulsive thrust greater than the weight of the aircraft. Only the application of powerful atomic engines will make it possible for vertical take-off of heavy aircraft. For this purpose, it is more advantageous to apply atomic turboprop engines because during vertical take-off they can create 30-40 percent more propulsive thrust than can turbojet engines provided the reactor power is the same. Moreover, the propellers push the air with less speed than the turbojet, and as a consequence the destruction of the airfield by the airstream will be less.

The vertical take-off of an atomic aircraft will be easier to achieve by keeping the aircraft in the horizontal position and to rotate on the engines to a vertical position. After altitude and speed has been gained, the engines can be placed gradually into a horizontal position. During landing, the engines can again be put in a vertical position, and by changing the propulsive thrust the pilot can gradually land on the ground.

Looking at the economics of the application of aircraft with atomic engines, first of all the expense of the nuclear fuel should be calculated. As was shown previously, the utilization of enriched uranium nuclear fuel, or the isotopes plutonium-239 and uranium-233, is favorable. Assuming that one gram of nuclear fuel, in heat value, is equal to 2 tons of kerosene, then the expense of the nuclear fuel used during the service life of an aircraft will be equal to the cost of the kerosene for such an aircraft, computing this in terms of American prices. However, only a small part of the total fuel loading in the nuclear reactor will be used up--the extra amount added for combustion. For a thermal neutron reactor this extra amount represents only a few percent of the original loading; for a fast reactor it is still smaller. Consequently, the expense of the nuclear fuel will be larger than the expense of the kerosene, for both the thermal neutron reactor and the fast neutron reactor. It is true that the remaining nuclear fuel can be purified at plants of the atomic industry and may be used again to load a reactor. This, though, does not decrease the original cost of an atomic engine using nuclear fuel; it does, however, significantly increase the competitiveness of atomic aircraft.

The absence of the operational costs of refueling before each flight, the increase in flight speed, the possibility of non-stop flights for long distances, and other advantages point out that utilization costs in the operation of nuclear engines sharply decrease. The economy which is obtained as a result of lower operating costs may make up for the higher construction costs of aircraft with such engines; then their application will be advantageous from the economic viewpoint.

The cost calculations printed in French literature confirm this conclusion. The cost of an atomic passenger aircraft with a gross weight of 15 tons, designed for transporting 180 passengers at a speed of 1,600 km/hr for a undetermined distance is approximately 9 billion francs. On the other hand, the cost of the contemporary large passenger aircraft "Comet III" is only 700 million francs. A comparison of costs is clearly against the atomic airplane; however, the annual savings obtained from the decrease in operational costs should reach 5 billion francs for each atomic airplane. It can be expected that atomic aircraft will pay off their construction costs.

Ground servicing of an atomic aircraft will also have its own peculiarities. An aircraft reactor which is not surrounded by a unit protective shield excludes the possibility of a person's presence near such an aircraft. Therefore, in case a "shadow" shield is employed, the reactor should be removed from the aircraft by means of remote handling equipment and lowered into a deep underground shelter. Only then could the passengers and pilots leave the cabin. The reactor will be mounted on the aircraft just before the take-off, when the passengers and pilots are seated in the airplane.

Only after the reactor is removed from the aircraft will the maintenance crew be able to check it in the usual way and be able to prepare it for the next flight. The reactor, after being placed in a deep underground shelter, will be checked by a television or optical system. The tightening of bolts and other maintenance operations will be accomplished by remote control.

The airfield designed for atomic aircraft probably will have underground facilities, or above-ground facilities with thick concrete walls. In these facilities persons will find protection from the reactor's radiation at the time of take-off and landing, when the distance to the operating reactor is less than a safe one.

Conclusions

We have examined the possible arrangements of atomic engines. We have acquainted ourselves with the principles of aircraft with atomic engines. No doubt the reader will raise the questions: When should the first flight of an atomic airplane be expected? What are the practical achievements in the areas of application of atomic engines in aviation? According to their degree of optimism, different authors of articles give different dates for the first flight on nuclear fuel, but all agree on the following: the progress on the construction of an atomic airplane is beyond the purely theoretical boundaries and has passed into the experimental phase, construction development, and experimentation of separate components and assemblies. At the present time we are at the entrance of the next phase--the construction of an experimental prototype of an atomic airplane.

Aggressively oriented American military circles expect that an aircraft with atomic engines will have no substitute for the delivery of atomic or hydrogen bombs to any part of the world. In the USA work has been conducted for many years in the field of application of atomic energy in aviation specifically for the construction of such airplanes. For an appreciation of the magnitude of this work, many examples can be presented from the American and English literature. All work connected with atomic energy in the USA is carried out under the control of the AEC. In the last year or two the work on the atomic airplane has been increased. A large part of the Commission's appropriations were utilized in fiscal year 1957 for this work. The aircraft construction company Convair worked on an aircraft on which an atomic engine from the General Electric Company would be installed. The latter has announced that it has built and carried out experiments on an atomic engine for military aircraft. The fact that ground experiments of an atomic turbojet engine have been carried out in the USA has been confirmed by the American General Advisory Committee on development of application of atomic energy for industrial purposes.

Work on the application of atomic energy in aviation is carried out also by other companies which work on separate development problems.

Other capitalistic countries do not have the strength to compete with the USA but in some of them, e.g., Great Britain, France, and Canada, work is conducted towards the application of atomic engines in aviation.

Soviet engineers are successfully solving the problem of increasing the speed and flight range of aircraft using ordinary fuel. In addition to this, the wide perspectives opened by the application of atomic energy in aviation make this area also attractive for our designers. At the present time it is not possible to tell the date of the first flight of an atomic aircraft, but there is no doubt that such a flight will take place. The future will reveal whether an atomic aircraft will have practical value or whether its construction will remain only an expensive experiment.

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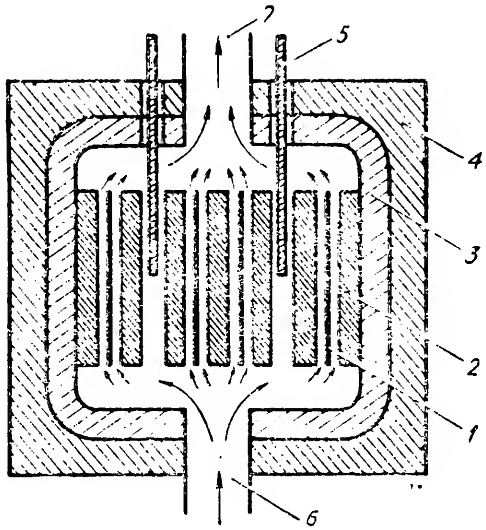

Fig. 1. Schematic of a heterogeneous nuclear reactor: 1. nuclear fuel; 2. neutron moderator; 3. neutron reflector; 4. shield; 5. control rod; 6. coolant entrance; 7. coolant exit.

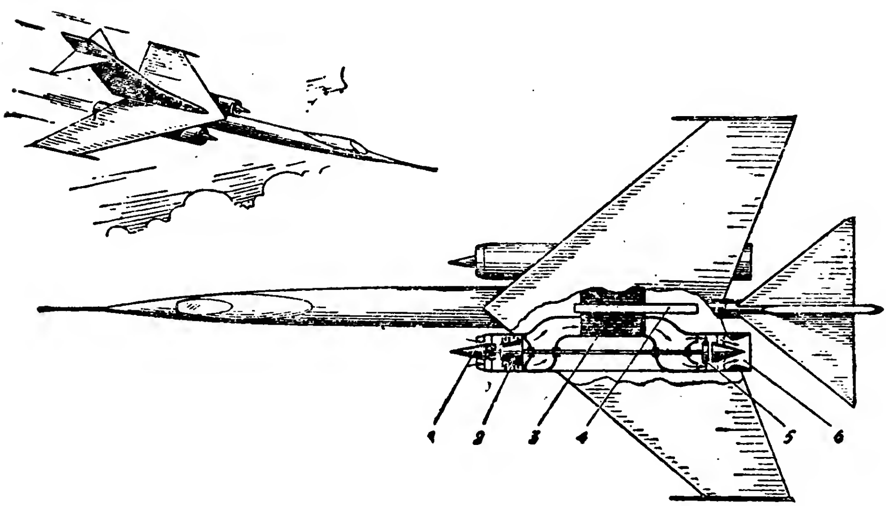

Fig. 2. General view and schematic of an aircraft with two atomic turbojet engines: 1. inlet cone; 2. compressor; 3. reactor; 4. control rod; 5. turbine; 6. jet nozzle

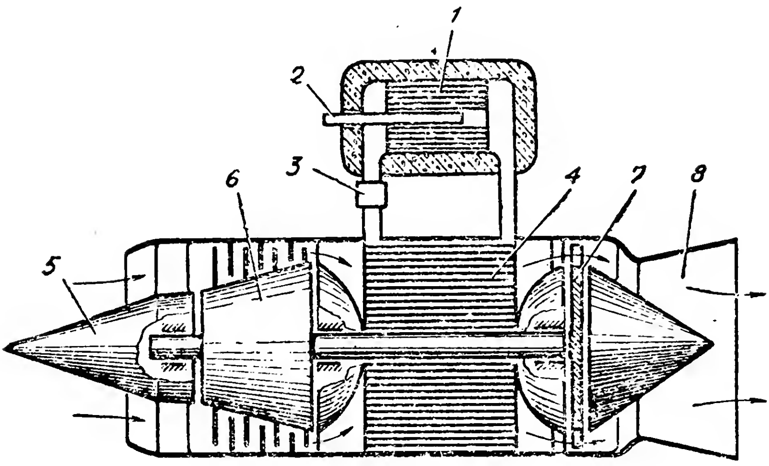

Fig. 3. Schematic of an atomic turbojet engine with liquid-metal heat exchanger: 1. reactor; 2. control rod; 3. liquid metal pump; 4. heat exchanger; 5. inlet cone; 6. compressor; 7. jet nozzle.

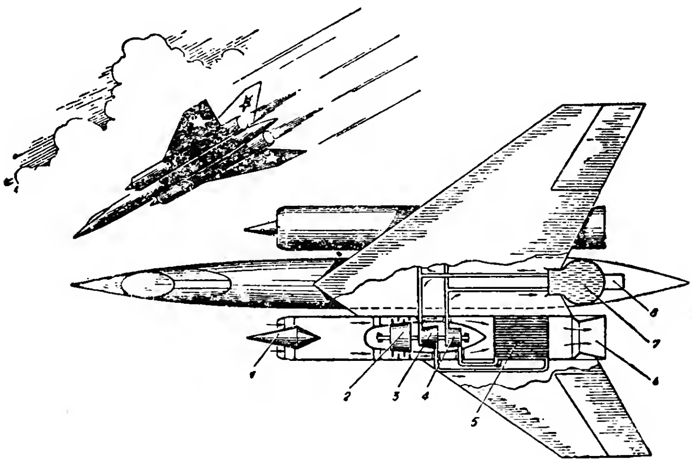

Fig. 4. Schematic and general view of an aircraft with two atomic compressor-drive engines: 1. inlet cone; 2. air compressor; 3. gas turbine; 4. gas compressor; 5. heat exchanger; 6. jet nozzle; 7. nuclear reactor; 8. control rod.

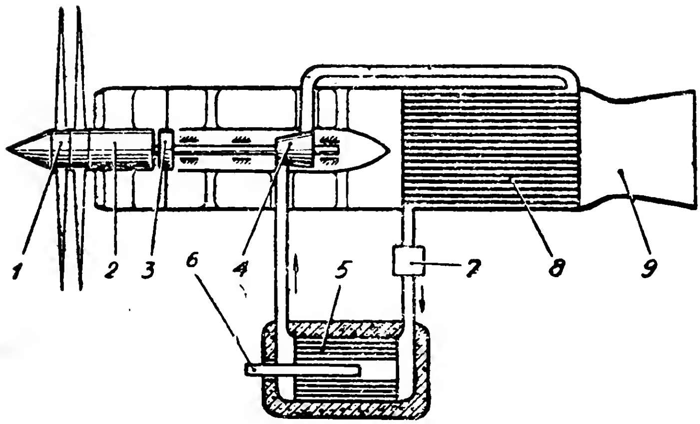

Fig. 5. Schematic of an atomic turboprop engine with mercury turbine: 1. propellers; 2. reduction gear; 3. air compressor; 4. mercury turbine; 5. reactor; 6. control rod; 7. mercury pump; 8. condenser; 9. jet nozzle.

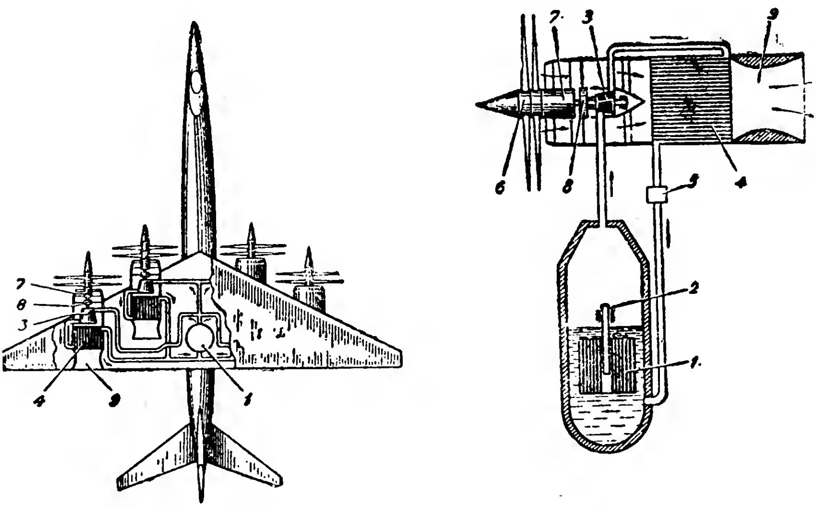

Fig. 6. Schematic of an aircraft with a boiling-water reactor and steam turbine engines: 1. boiling-water reactor; 2. control rod; 3. steam turbine; 4. condenser; 5. water pump; 6. propeller; 7. reduction gear; 8. air compressor; 9. jet nozzle.

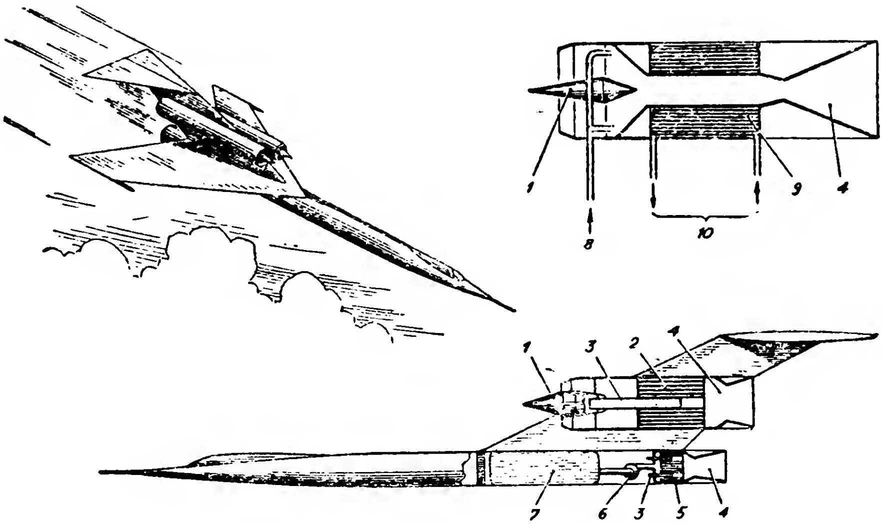

Fig. 7. Schematic and general view of an aircraft with two atomic ramjet and one atomic rocket engine: 1. inlet cone; 2. reactor for ramjet engine; 3. control rod; 4. jet nozzle; 5. reactor for rocket engine; 6. pump; 7. hydrogen tank; 8. ducts for gaseous nuclear fuel; 9. moderator; 10. reactor coolant.

TRANSLATION

APPLICATION OF ATOMIC ENGINES IN AVIATION

(PRIMENENIYE ATOMNYKH DVIGATELEY v AVIATSII)

By G. N. Nesterenko, A. I. Sobolev, Yu. N. Sushkov

Military Press of the Ministry of Defense of the USSR
Moscow, 1957

PREPARED BY
TECHNICAL DOCUMENTS LIAISON OFFICE
MCLTD
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

To The Reader:

The Military Press requests that you send your comments on this book to the following address: Management, Military Press, 18 Tverskaya Boulevard, Moscow 104

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Sushkov, Yuriy Nikolayevich
"Application of Atomic Engines in Aviation"

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Col.Dr.Eng. M.L.Novikov, Engineer
Art Editor: G.V.Grechikho; Cover Artist: B.S.Ivanov
Production Editor: M.A.Strel'nikova; Proofreader: L.K.Tsvetkova

S.K.Timoshenko Printshop No.1
of the Management of the Military Press of the USSR Defense Ministry
3 Skvortsov-Stepanov Lane, Moscow K-6
Price 2 rubles 60 kopeks

INTRODUCTION

One of the most outstanding scientific achievements of our day has been the discovery of atomic energy and of practical methods of obtaining and applying it. We have already entered the Atomic Age. Atom, atomic energy, atom bomb, atomic power plant, atomic icebreaker: these are terms and words that may be heard everywhere today.

Atomic energy is having a major influence on the development of science and engineering.

As soon as it became clear that the chain reaction of fission of the uranium nucleus could produce an explosion of enormously destructive force, the imperialists hastened to apply this discovery to military purposes. During World War II the United States of America was able to gather "atomic secrets" from the entire capitalist world, mobilize scientists and engineers and, by the outlay of enormous funds, make the atom bomb.

The ruling circles of the United States marked the beginning of the Atomic Age by the barbaric destruction of the Japanese cities of Hiroshima and Nagasaki, although there was no military necessity for this whatever. The United States frankly made use of the termination of the World War II to proclaim the unprecedented power of the atomic weapon, to threaten the peoples of the world with a "new force", on which the United States seriously believed to have a monopoly. Everyone knows what happened to the "monopoly" of the atomic bomb and later of the hydrogen bomb. The

Soviet Union did not permit itself to be frightened by bombs of whatever kind, but, exercising constant concern for its security, it created its own atomic and thermonuclear weapons.

The Twentieth Congress of the Communist Party of the Soviet Union noted once again that the Soviet people, engaged in peaceful labors, is forced to reckon with the military preparations in the capitalist countries.

In the development of the Soviet Armed Forces we proceed from the conviction that the means and forms of war in the future will differ considerably from all wars of the past. If a war should come in the future, it will be characterized by mass use of military aircraft, a variety of rocket weapons, and various means of mass destruction such as atomic, thermonuclear, chemical, and bacteriological weapons.

However, the various types of the most modern arms, including the means of mass destruction, do not diminish the decisive significance of the ground, air, and naval forces. Without strong ground forces, and without strategic, long-range, and ground-attack aircraft and a powerful navy, it is impossible to wage modern war successfully.

Thanks to the constant concern of the Communist Party and the Soviet government with the defensive capability of our country, the Soviet Armed Forces have been basically reorganized and have advanced far in quality from the level they had attained at the end of the Great Patriotic War. The increasing capabilities of the Soviet economy and the major accomplishments of heavy industry in particular have made it possible to re-equip our army, air force, and navy with first-class military technology.

The share of the Military Air Forces in the total make-up of our Armed Forces has considerably increased. The Soviet Armed Forces are in possession of first-class aviation, and powerful rocket and jet armament of various classes, including long-range rockets.

In view of the continuing progress of science and engineering and the develop-

ment of new means of destruction and new military technology, it is our duty constantly to perfect our knowledge, to study and master the most desirable methods and forms of the conduct of military operations under conditions in which modern means of armed combat - including the very latest - are employed.

Today's strategic bombers with chemical-fuel engines are capable of nonstop flights of many thousands of kilometers. They are capable of successfully solving military problems at a considerable distance from their bases, in the deep rear of the enemy. However, the range of modern bombers is limited by the amount of fuel that can be stored aboard. In this connection, aircraft with atomic engines, whose range will considerably exceed that of today's aircraft, are of particular interest.

In recent years, work on producing atomically powered aircraft has been done on a large scale in the capitalist countries. The significance ascribed to this work by the government of the United States now and in the past is obvious from an official report to the Congress of the United States on this matter: "In case of war ... atomic aircraft engines will play a role equal to that of the atom bomb itself. The limitations of range imposed by any chemical fuel greatly complicate the aerial delivery of atomic bombs over long distances. Therefore, if the United States possessed atomic aircraft engines in addition to the atom bomb, this would be a decisive factor".

Thus, after the creation of atom and hydrogen bombs, the American imperialists consider the next stage in their program the development of intercontinental bombers and rockets with atomic engines, to be used to deliver bombs of enormous destructive power to any point on the earth's surface.

In order to perform theoretical investigations in the field of atomic engines for aircraft, special plans and research organizations have been developed in the United States and England, and a number of major scientific research laboratories, scientists, and companies have been drawn into this activity.

At the present time more than ten aircraft engine manufacturers are engaged in

the United States on the production of atomic aircraft engines and reactors: These include such important companies as General Electric, Pratt & Whitney, General Motors, and others. The Lockheed, Convair, Boeing and other aircraft-building firms are engaged in producing a glider for an aircraft, with an atomic power plant.

The overall control of all the work in this field is in the hands of the United States Atomic Energy Commission and the Command of the Air Force.

The Soviet Union has been compelled, in view of the military preparations of the capitalist countries, to develop armed forces capable of repulsing an attack by an aggressor at any time. Our scientists, designers, and engineers have been giving and are giving much effort to the reinforcement of the military strength of our homeland and to the uninterrupted perfection and progress of Soviet military science and engineering.

The Soviet people is moving successfully along the road of building communism in our country. An important step along that road is the fulfillment of the Sixth Five-Year Plan. Much attention is being given, during the Sixth Five-Year Plan, to the peaceful use of atomic energy. In the period from 1956 to 1960, new atomic power plants of large capacity will be built, atomic power plants for transportation purposes will be further developed, and an icebreaker with an atomic engine will be built.

Speaking before the Twentieth Congress of the Communist Party of the Soviet Union, Academician I.V.Kurchatov stated: "The use of atomic energy for transportation purposes has to be further expanded.

"During the present Five-Year Plan, work on atomic power plants not only for an icebreaker, but for other vessels, for air and land transport has to be developed on a large scale ...".

At the present time, science and engineering are on the verge of creating aircraft with atomic engines. The possibilities of such aircraft are being studied, the economic benefits, advantages and disadvantages of atomic aviation of the future

are being investigated, and a broad program of experiments and experimental work is being conducted. An increasing volume of literature, scientific and popular scientific books and articles, deal directly or indirectly with the problems of developing atomic power plants for aircraft and rockets. Extensive theoretical research is being done on the problem of the use of atomic energy for interplanetary flights.

The purpose of the present pamphlet is to systematize the scattered data in the literature on the utilization of atomic power plants in aviation and rocket engineering and to review these data in popular form, accessible to wide groups of readers.

CHAPTER I

PERSPECTIVES FOR THE USE OF ATOMIC ENERGY IN AVIATION

The discovery of atomic energy and, later, the development of practical means of producing and utilizing this energy is one of the most important scientific achievements of today. In order to conceive of the full significance of this remarkable discovery it is enough to remember that throughout all history the question of the sources of energy used for actuating machines has been one of the most important factors tending to either retard or accelerate the development of technology.

Thus, the appearance of the steam engine converting the energy of fuel into mechanical motion resulted in an industrial revolution leading to a development of science and technology without precedent to that day. The invention of internal combustion engines at the end of the Nineteenth Century made possible the creation and development of the automobile industry and aircraft. At the beginning of the Twentieth Century electrical energy began to play an enormous role.

Whenever a new source of energy has come into use, the productive forces of society have made giant strides forward.

At present, we are witnesses to the beginning of a new epoch in the history of human society, that of utilization of the energy locked in the atomic nucleus.

The prime source of all types of energy, and the source of life on earth has hitherto been solar energy. It is known that this energy is the result of nuclear transformations occurring in the enormous mass of the sun. Scientists believe that on the sun there occurs the fusion of hydrogen nuclei to helium nuclei, accompanied

by the release of colossal amounts of atomic nuclear energy. Modern science has begun to obtain and utilize atomic energy under terrestrial conditions, which has opened new possibilities for the development of productive power.

We are on the threshold of a new scientific, engineering and industrial revolution, far exceeding in significance the industrial revolutions that followed the discovery of steam and electricity.

The introduction of atomic energy into industry and transport will proceed by stages governed by the difficulty of the engineering and technical solutions of the problems encountered. The first stage, relatively simple and easy to reach, was the development of atomic power plants. The second stage was the formulation and solution of the problem of development of sea-going vessels with atomic power plants. The third stage is the use of atomic energy in aircraft engines. This problem has proved to be one of the most difficult for technical realization and therefore has not yet found a practical solution. Further serious efforts are required for its solution.

However, history has shown that when a new and more powerful source of energy is found, its practical application wherever it is most needed is something that will of necessity occur in the not-too-distant future. The present-day rapid development of nuclear physics and power engineering, the development of the atomic industry, the experience acquired in theoretical and experimental research on stationary atomic power plants have made it possible for Soviet and foreign scientists, engaged in the development of atomic aircraft power plants, to proceed even today from scientific and purely theoretical research to the engineering calculations and experiments required.

The development of aviation is primarily governed by the development of the aircraft engine industry. The speeds, altitudes, and ranges of aircraft attained are largely dependent upon the perfection of aircraft engines: their power, operational ceiling, economy, reliability in operation, weight, and dimensions. Figure 1

presents an interesting graph, reflecting the opinions of a number of foreign scientists with regard to the development of aircraft engines. This graph shows that the potential possibilities of development of internal combustion and, later, of turbojet engines (TJE) have already been exhausted to a considerable degree, while the development of turboprop engines (TPE) is now rapidly under way, as is that of liquid-fuel jet engines and ram-jet engines (LJE and RJE). According to this graph,

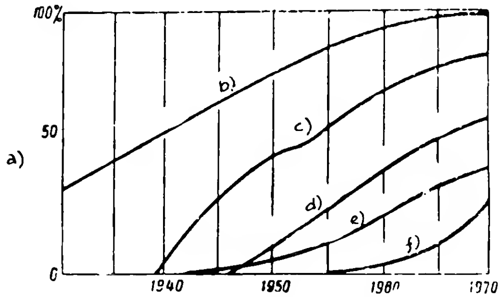

Fig.1 - Graph of the Development of Aircraft Engines in Conventional Percentages

a) Percentage of potential development attained; b) Internal combustion engines; c) Turbojet engines; d) Turboprop and turbojet engines with after-burners; e) Liquid-fuel and ram-jet engines; f) Atomic engines

1955 may be regarded as the year of the beginning of development of atomic aircraft engines, and they should make their appearance in the very next few years. However, it is true that thus far it is difficult to assert whether the curve of development of atomic aircraft engines will continue as smoothly and sharply upward as indicated by the graph. It is still possible that there will be plateaus and uneven segments, depending on the success or failure of experiments under way, new discoveries, and other attendant factors.

Wherever the problem of the creation of a new type of engine arises, a new

question is posed: in what respect is it better and superior to those we already have at our disposal? Why do we need atomic aircraft engines?

This question may be answered if we examine certain general perspectives of the development of aircraft engineering: primarily the prospective increase in range of aircraft, and questions having to do with the supply of chemical fuels for aircraft.

Range of Aircraft Using Chemical and Nuclear Fuels

The constant effort to increase the range of aircraft and helicopters employing chemical fuel is encountering ever greater difficulties, sometimes insurmountable.

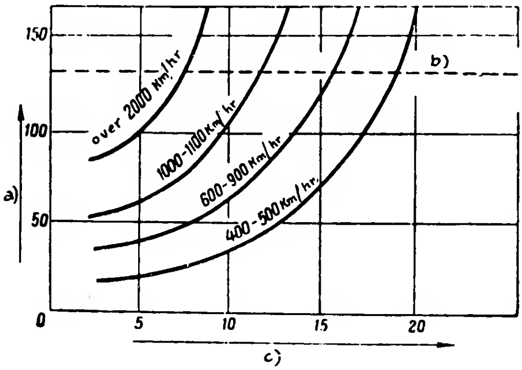

Fig.2 - Ratio of Weight of Aircraft to Range and Flying Speed

a) Weight in tons; b) Aircraft with atomic engines (over 2000 km/hr);

c) Flying range in 1000 km

It is particularly difficult to provide adequate range for modern transonic and supersonic aircraft. The increase in speeds is attained primarily by increasing the engine power, and greater power results in greater fuel consumption. It suffices to say that a modern fighter aircraft weighing 6 - 8 tons and flying at supersonic speed, consumes 150 - 200 kg of kerosene per minute. Consequently, in an hour of

flight such a fighter aircraft requires 9 - 12 tons of fuel. It is impossible to store this much fuel in a fighter aircraft, and therefore the range and duration of flight of fighter aircraft operating on chemical fuels is difficult to increase.

Designers have long known the relationship between speed and range, on the one hand, and weight of an aircraft on the other. The study of an approximate graph of this relationship (Fig.2) shows that, in the attempt to increase the range at a given flying speed, the designer is compelled to increase the flying weight of the aircraft and the percentage of the fuel weight within the total weight. The heating value of modern chemical fuels such as kerosene and gasoline is 10 - 11,000 kcal/kg. This comparatively low heating value limits the range of aircraft, particularly of rockets, in which it is often necessary to have a large supply of oxidizer in addition to a large reserve of fuel. The overall heating value of rocket fuels (fuel plus oxidizer) is 2000 - 3000 kcal/kg. As a result, long-range aircraft have come increasingly to resemble flying tank cars. This is true of rockets to an even greater degree. We need only note that the total fuel capacity of a modern long-distance bomber is 50 - 100 tons and more. Tens of tons of fuel are required to fuel the latest transport and passenger aircraft equipped with powerful jet engines.

An approximate calculation of the range of supersonic aircraft now in the project stage shows that aircraft weighing up to 100 tons and flying at 2000 - 3000 km/hr will have a maximum range of 3000 - 5000 km. The heaviest aircraft (200 - - 250 tons) flying at these speeds will have ranges of 10,000 - 12,000 km, i.e., their radius of action will be 5000 - 6000 km. The weight of aircraft with atomic power plants, as shown in Fig.2, is relatively independent of the range and flying speed. According to opinions now held, the weight of the first aircraft with atomic engines will be 100 - 150 tons, and these aircraft will be able to fly any required distance over the surface of the earth.

Is it possible to increase the range of aircraft operated on chemical fuel? Yes, this is entirely possible. In recent years, numerous experiments have been

conducted in this field with the object of refueling aircraft in flight.

The idea is not new. As early as 1929, K.E.Tsiolkovskiy suggested that cosmic speeds can be attained by using so-called cosmic rocket trains instead of single rockets. A rocket train consists of a number of rockets each of which, as it becomes exhausted, transfers its residual fuel to the subsequent rocket, is then separated, and returned to earth. As a result, the last "car" of a rocket train, i.e., the final rocket, is enabled to attain cosmic speeds.

Refueling in air, as practiced today, is the application in aviation of the idea of this type of rocket train. The essence of this measure consists in classifying aircraft into groups - primary aircraft and tanker aircraft, which makes it possible to increase the range of the primary aircraft by transferring fuel to it from the tanker in the air at a given distance from the earth. Figure 3 illustrates a simplified variant of air refueling. Let us imagine three aircraft, each of which

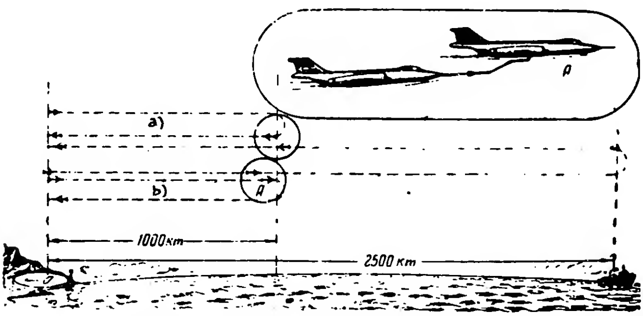

Fig.3 - Refueling of Aircraft in the Air with the Object of Increasing Its Range

a) Refueling rendezvous; b) Refueling pass

has a maximum range, at full tanks, of 3000 km. The first two completely fueled aircraft take off: a primary aircraft and a tanker. Having flown approximately

one-third of its total range, i.e., about 1000 km, the tanker establishes connection with the other aircraft by a special hose or flying boom and transfers one third of its kerosene to the latter. The tanker then returns to its home base on the remaining third of the fuel, while the primary aircraft, now again fully fueled, is capable of flying another 1500 km forward, accomplishing a military mission and returning to a rendezvous with the other tanker at a distance 1000 km from its home base. Here, tanker No.2, retaining two thirds of its own fuel, transfers one third to the primary aircraft, and the two return to the airfield together. Thus the use of two tankers makes it possible to increase the radius of action of the third aircraft by 60 - 65% under ideal conditions.

In order for aircraft in flight to rendezvous dependably, both in terms of location and time, and in order for the fuel to be transferred in flight, special training and high skill on the part of the air crews is necessary. Therefore, the refueling of aircraft in flight may be classified in the category of necessary half-measures which, in the first place, are exceedingly complicated and expensive and, in the second place, do not provide any significant increase in range. In addition, the refueling of aircraft in the air at supersonic speeds is a practical impossibility. Before being refueled, an aircraft must slow down to subsonic speed and then, in order to return to supersonic speed, it will require almost as much fuel as can be gained by refueling. Increases and decreases in the speed and altitude of supersonic aircraft very sharply reduce their range, since each successive acceleration and climb results in increased fuel consumption.

Considerable increase in range may be attained by aircraft, without refueling, only if nuclear-fuel-engines are used, since nuclear fuel contains approximately two million times as much energy per unit weight as does an equal unit weight of modern aircraft fuels.

The design, i.e., the calculated range of aircraft with atomic power plants is not determined by the fuel supply but by the engine life, i.e., by the number of

hours the engine can operate before wearing out or before failure of its weakest structural parts and also by certain other factors, such as fatigue of the crew, etc. According to certain data from other countries, the range of a single flight of an atomic aircraft is of the order of 90,000 - 100,000 km or more. Moreover, adjustments in the speed and altitude of the aircraft will not greatly effect its range, since the consumption of nuclear fuel under any conditions of flight is rather small.

Calculations show that an aircraft having a flying weight of 120 tons, cruising at 2000 km/hr at constant 20% efficiency, will consume approximately 25 grams of uranium ^{253} per hour. Therefore, a flight round the world (40,000 km in 20 hours) by such an aircraft would require the consumption of no more than 500 - 600 gm of nuclear fuel.

In order to make the same flight with chemical fuel, more than 1000 tons of kerosene, or 20 railway tank carloads would be required. The aircraft would have to make approximately 15 landings for refueling purposes. Due to the consumption of kerosene in flight, the amount of fuel needed per hour will decrease as the aircraft gradually becomes lighter. However, this apparent advantage is completely canceled by the increased fuel consumption for the next following take-off, for gaining altitude and speed after each landing en route.

The attainment of supersonic speeds by heavy aircraft requires exceedingly high thrust and power of the power plants. A power of the order of 150,000 - 200,000 hp and more is required. Designing aircraft engines of such power for use with chemical fuel encounters numerous difficulties. In principle, greater power may be attained more readily in atomic power plants than in conventional aircraft engines.

The prospects for the creation of high-power atomic aircraft engines and particularly the prospects for ensuring any desired range are naturally quite intriguing. However, they are misleading as far as military aircraft is concerned, where such problems as increased speed, altitude, and range will never cease to be impor-

tant. The possibilities are even more appealing as far as use of such aircraft for peaceful purposes is concerned: passenger and transport aircraft. We will discuss these prospectives in greater detail in examining a number of projects for atomic aircraft; for the time being, we will draw the conclusion that to attain a further sharp increase in range of modern high-speed aircraft, engines operating on nuclear fuel will be required.

Preserving the World Petroleum Reserves

The second important problem compelling the use of atomic energy in aircraft engines is the problem of the excessive depletion of the world petroleum resources and the difficulty of providing an adequate supply of chemical fuels for aviation.

The modern jet engine is one of the most important consumers of the higher fractions of oil refining: kerosene and the best grades of gasoline. The intensified consumption of the world petroleum resources for combustion in transport and power-producing power plants is regarded by science as a matter of necessity and not at all of wisdom. Petroleum is a most valuable organic raw material for various branches of industry: mechanical, paint, and many others, including the food industry. Long ago, the great Russian scientist, D.I.Mendeleyev, spoke of petroleum as being "black gold" and, speaking of the barbaric inroads made on the resources of petroleum, said with deep emotion: "Let us rather burn our stock certificates".

The cost of producing, refining, and transporting petroleum, and the cost of aviation fuels derived from it, is comparatively high. In addition, the world resources of petroleum are not inexhaustable. Statistics show that at the present level of consumption of petroleum, the world reserves may be exhausted within 185 years. If we take into consideration the uninterrupted growth in the total capacity of power plants operated on chemical fuels, calculations show that the depletion of oil reserves will be felt within 25 - 50 years.

This type of calculation cannot, of course, claim to be completely correct and

accurate, since depth prospecting for oil is revealing new oil deposits, but the figures demonstrate nonetheless that the world reserves of petroleum are very definitely limited. If conversion of aviation from chemical to nuclear fuels is successful, the petroleum reserves will not be depleted as intensively: more petroleum will be freed for satisfying other pressing needs of the national economy.

The above facts raise the question of world resources of nuclear fuels, the cost of nuclear fuel, its capacity as a source of energy, and so forth.

Let us deal with these questions and attempt to analyze them. It need only be borne in mind that the process of discovery and assaying of the world resources of nuclear fuel and of its possibilities in terms of power generation is far from being complete. The dynamics of this process will become clear from a study of the relatively short but very exciting history of the discovery of the various sources of atomic nuclear fuel.

Two Major Methods of Obtaining Nuclear Energy

Despite the fact that the past several years have been marked by a rapid development of atomic power production, science does not have sufficiently complete data on the nature of the forces acting in the nucleus of the atom.

The single fact that the nature of nuclear force is not clearly understood or fully studied is no obstacle for the practical utilization of nuclear energy. The British physicist, O.Heaviside, once said, "Am I going to refrain from eating dinner just because I do not completely understand the process of digestion?" However, in order to understand the methods of obtaining atomic energy it is necessary to review briefly the properties of the atomic nucleus and atomic energy.

The atomic nucleus consists, as we know, of protons and neutrons which together are called nucleons. Nucleons are retained in the nucleus by special nuclear forces of attraction that keep them in fixed positions relative to one another. These forces are complex in nature. At present, all that has been firmly established is

that nuclear forces are neither gravitational or electromagnetic. It is also known that nuclear forces are "short-range" forces and exist only in the nucleus itself. It is rather easy for us to conceive of the manner in which the molecules of liquid constituting a drop of liquid are mutually attracted. The forces within the nucleus are externally similar to the forces of molecular attraction in liquids. At the surface of the nucleus they create an effect similar to the surface tension in a liquid. This leads to the development in the nucleus of a kind of "surface tension" which gives the nucleus its spherical form. The nucleus is like a drop of positively charged liquid. But the forces of molecular attraction are tens of millions of times smaller than the forces of nuclear energy. Therefore, a comparison of the atomic nucleus with a drop of liquid is only a very crude approximation.

Now let us examine the energetics of nuclei and nuclear forces. Not possessing adequate information as to the nature of nuclear forces, modern science is nevertheless able to determine the nuclear binding energy, depending on the existence of these forces.

The nuclear binding energy - the energy which must be expended to perform the work of dissociating the nucleus into its component nucleons - has to overcome the action of nuclear forces.

In the reverse process, in the formation (fusion) of a nucleus from nucleons, a similar energy is released. Thus, the binding energy may be defined as the energy which is released in the formation of the nucleus from nucleons.

The unit most widely employed in nuclear physics is the electron-volt (ev). We will have to refer to this unit of energy repeatedly so that it is useful to familiarize ourselves with it. One electron-volt is equal to the energy acquired by a particle whose electric charge is equal to the charge on an electron as it passes through an electric field having a potential difference of one volt. In practice, larger units are employed more frequently. These units are derivatives of the electron-volt: 1000 electron volts (the kiloelectron-volt or Kev) and 1,000,000

electron-volts (the mega-electron-volt or Mev).

The binding energy possessed by a single nucleon is not identical for nuclei differing in atomic weight (Fig.4). The greatest binding energy possessed by a single nucleon is found in nuclei whose atomic weights range from 40 to 80. This is the atomic weight of the nuclei of iron, nickel, krypton, and certain other ele-

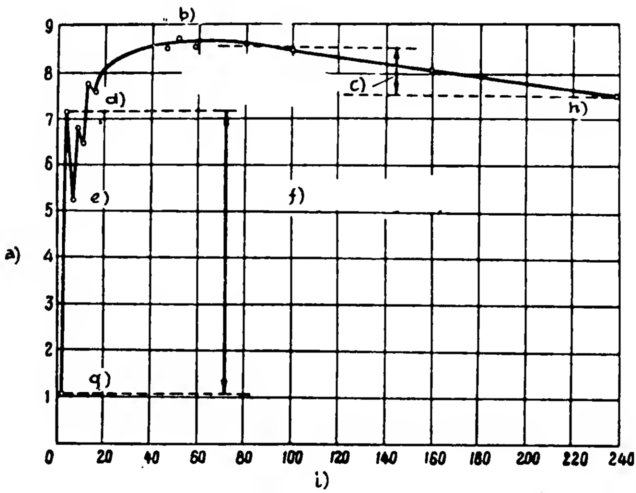

Fig.4 - Ratio of Energy per Particle in the Nucleus to the Atomic Weight
a) Binding energy per nucleon, in Mev; b) Fission "fragments"; c) Energy released in the fission of the uranium nucleus per nucleon; d) Helium; e) Lithium; f) Energy of nuclear fusion of helium from hydrogen per nucleon; g) Hydrogen; h) Uranium; i) Atomic weight

ments. The binding energy per nucleon of heavy hydrogen is approximately 1,000,000 electron-volts (one Mev). As the atomic weight increases, the binding energy per nucleon rises rapidly in the light elements to a maximum (about 8.75 Mev) in the elements having an atomic weight of about 60 (iron and nickel), and then

gradually declines to a value of the order of 7.5 Mev in the elements at the end of Mendeleyev's periodic table.

As shown by the graph (Fig.4) the binding energy per particle increases as it moves along the curve to the center from both sides, i.e., from the lighter and from the heaviest elements. The result is that there will be two basic types of nuclear transmutation (reactions), proceeding with the liberation of energy: the reaction of fusion of the nuclei of light elements taking the form of what is known as thermonuclear reactions, and the reaction of fission of heavy nuclei into nuclei of medium weight - the reaction of fission.

The energy released per unit weight of the initial product in thermonuclear reactions of the light elements is several times larger than that in the fission of nuclei of heavy elements. At present, it is fission reactions that man has learned to control. Control of thermonuclear reactions such as to permit their practical application has not yet been attained and is a matter for the future. Therefore, we will mainly discuss here fission reactions which dissociate various materials, their resources, and their power potentialities.

The major fissionable material (nuclear fuel) at present is uranium. Let us describe the basic properties of uranium that make it possible to use it as a "fuel" for transport power plants.

Uranium is a bright metal, softer than steel, with a specific gravity of 18.95, and can be worked by any mechanical method. A specific feature of uranium is its high susceptibility to oxidation. At a temperature as low as 100°C, uranium is capable of combustion and rapidly burns in an oxygen atmosphere. In an ordinary chemical reaction, the heat value of uranium is very low and does not exceed 1075 cal/kg. The fusing point of uranium in an inert medium is 1130°C. This comparatively low fusing point and the structural transformations occurring in uranium at various temperatures have caused considerable difficulty in designing high-temperature reactors for power plants for use in transport.

The fission reaction of the nucleus of uranium^{235}, shown in rough outline in Fig.5, takes place as follows: A free neutron penetrating the nucleus brings it into a state of excitation. This destroys the equilibrium of the nucleus, causing

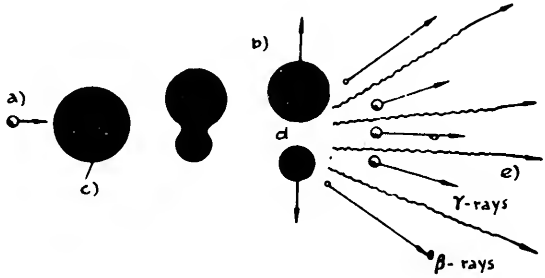

Fig.5 - Fission Reaction of Uranium^{235} Nucleus

a) Free neutron; b) Intermediate excited stage; c) Nucleus of Uranium^{235}; d) Fission "fragments"; e) Secondary neutrons; f) Gamma rays; g) Beta rays

it usually to divide (split) into two unequal "fragments". This results in an expulsion of two or three new neutrons, known as secondaries.

A portion of the energy locked in the uranium^{235} nucleus (nuclear energy) is converted into kinetic energy of the flying "fragments" and into radiant energy of various types. The Table given below provides an approximate picture of the energy balance of a nuclear fission reaction.

Thus the bulk of the energy, comprising approximately 166 Mev per fission, is that of the "fragments". The "fragments" fly off in various directions at tremendous speeds, collide with surrounding nuclei and, increasing the speed of their chaotic thermal motion, heat the medium in which the process of nuclear fission is taking place. Conversion of the kinetic energy of the "fragments" (at nuclear fission of 1 kg uranium^{235}) into units of heat energy produces approximately 17.4 bil-

lion kcal and the total energy release from the fission of one kilogram uranium^{235} is 19.7 kcal. Complete combustion of one kilogram of chemical aviation fuel (kerosene) yields only 10,300 kcal.

The tremendous difference in the quantities of thermal energy derived from nuclear and chemical reactions, respectively, is due to the fact that, in the ordinary combustion reaction, changes occur only in the electron shells of the atoms; no structural changes occur within the atomic nucleus. In nuclear reactions, a change (rearrangement) occurs in the nuclei themselves. Since the mass of a nucleus exceeds by thousands of times the mass of the electron shell of the atom of any element, the energy released in nuclear reactions is therefore greater. As early as 1905, the German physicist Einstein formulated a law that defined the quantitative mass-energy interrelation in nature. This law is expressed by the familiar equation

Table 1

Distribution of Energy of Fission of Uranium^{235} Nucleus

1. Kinetic energy of "fragments"	83%	166 Mev
2. Kinetic energy of secondary neutrons	3%	6 Mev
3. Total energy of direct gamma radiation	5%	10 Mev
4. Total energy of radioactive radiation of "fragments"	9%	18 Mev
	100%	200 Mev

$$E = mc^2,$$

in which E is the total energy of a body, in ergs;

m is the mass of the body, in grams;

c is the velocity of light, in cm/sec.

In accordance with this law, every change in the energy of a body involves a corresponding change in its mass, and vice versa.

In ordinary chemical combustion reactions, it is a practical impossibility to observe changes in the mass of the reacting substances. This is explained by the fact that the amount of energy being released is relatively small, and therefore the change in mass is negligible. For example, complete combustion of 100 tons of kerosene in an oxidation reaction involves the participation of approximately 1500 tons of air, and the total change in the mass of the combustion products due to the liberation of energy is only 0.03 grams. Naturally, to detect such a quantity in the total mass of reacting products (1600 tons) is impossible. However, the law of the mass-energy interrelation is demonstrated most strikingly in nuclear reactions, which are characterized by considerable changes in the energy of the nuclei and by a noticeable change in mass.

The law of the mass-energy interrelation is the basis of one of the methods of determining the "heating value" of nuclear fuel, and yields accurate quantitative results.

From the equation, $E = mc^2$, it follows that, for m = 1 kg, the theoretical value of the energy E (in thermal units) will be 21,600 billion kcal.

In the splitting (fission) reaction of nuclear fuel, the mass of the end products of fission is smaller than the mass of the initial substance by a definite magnitude, which may be called the mass defect (loss). Experimental and mathematical data have established that, for uranium^{235}, the mass defect per kilogram of substance is

$$\Delta m = 0{,}000911 \approx 0{,}001 \; \kappa g.$$

Thus, when all the nuclei in 1 kg of uranium^{235} have undergone fission, the mass of the end products of the nuclear reaction is almost one whole gram less than the mass of the initial substance before fission.

The amounts of energy released may thus be determined on the basis of the quantity of mass liberated (according to the mass defect). Since the total energy of 1 kg of the substance, as indicated above, is 21,600 billion kcal, the energy released in this case will be

$$Q = 21600 \cdot 0{,}000914 \approx 19{,}7 \text{ billion kcal}$$

This number is the heating value of uranium^{235}, i.e., the amount of energy released when all the nuclei in one kilogram of uranium have undergone fission.

It should be mentioned that the complete combustion of 1 kg kerosene liberates a total of 10,300 kcal, or approximately only $\frac{1}{2{,}000{,}000}$ as much.

A comparison of the heating value of nuclear fuel with that of modern chemical aviation fuels leads to the conclusion that the consumption of nuclear fuel will be a fraction of that of chemical fuel, for the same effective power of power plants. This fact offers the possibility of a considerable increase in the range of aircraft and rockets when using nuclear fuel.

Comparison of the World Resources of Chemical and Nuclear Fuels

On the basis of data published in the press, the prospected resources of chemical fuels and nuclear fissionable materials are approximately as follows:

Coal	2000 billion tons
Oil	25 billion tons
Uranium	0.01 billion tons

As we see, there is considerably less uranium in the earth than coal and petroleum. Nevertheless, despite this apparently unfavorable relationship in terms of weight, the margin of energy in uranium is approximately ten times greater than the margin of energy in coal and oil combined.

In order to get an idea on the distribution of uranium in nature, let us ex-

amine the content by weight (in percent) of certain metals in the earth's crust.

Copper	0.010% (100 gm/ton of earth)
Uranium	0.007% (70 gm/ton of earth)
Zinc	0.004%
Lead	0.002%
Gold	0.0000001%

It will be seen from these data that uranium is an element more widely distributed in nature than zinc, lead, and gold combined.

Natural native uranium is obtained from ores and is a mixture of three isotopes: uranium^{238} (99.282%), uranium ^{235} (0.712%), uranium^{234} (0.006%).

Only uranium^{235} is available as a fissionable material satisfying the requirements of power production. Uranium^{235} is capable of self-sustaining (chain) nuclear reaction, i.e., of effectuating an uninterrupted release of energy. But the very small content of the 235-isotope renders natural uranium unacceptable for use in power plants for purposes of transportation. It is necessary either to separate the uranium^{235} in its pure form or to enrich natural uranium with this isotope.

The process of separating the isotopes of uranium is to this day one of the most expensive and complex processes in the atomic industry. The problem of widespread use of nuclear fuel for power production would be hopelessly insoluble, because of the small amount of natural uranium^{235} and the difficulties of obtaining it in pure form, if there had not been discovered methods of obtaining artificial nuclear fuels from the natural resources of uranium^{238} and thorium^{232}.

Artificial nuclear fuels now available include the following: plutonium^{239} (obtained in special breeder reactors from uranium^{238}), uranium^{233} (obtained in reactors from natural thorium^{232}) and certain others.

In view of the fact that methods have been obtained for the application of artificial nuclear fuels, permitting the use of uranium^{238} and thorium^{232}, calcula-

tions of the energy resources in nuclear fuels have been made on the basis of natural uranium and thorium (see Table 2).

This Table shows that the total margin of energy in nuclear fuels is approximately 22 times as great as the total energy resources in all organic fuels combined.

Table 2

World Resources of Energy in Various Types of Fuel

Type of Fuel	World Supply	Energy Content
Coal	3,482 billion tons	21.10×10^6 billion kw-hrs
Oil	197 billion m^3	2.22×10^6 billion kw-hrs
Natural gas	15,850 billion m^3	0.17×10^6 billion kw-hrs
Uranium + thorium	0.026 billion tons	519.00×10^6 billion kw-hrs

In addition, there is reason to expect a considerable increase in the sources of nuclear fuels as a result of the discovery of new methods of fission and fusion of the nuclei of other chemical elements. At present, science has already discovered the possibility of experimental work toward controlled thermonuclear reactions with the light elements. A controlled thermonuclear reaction makes it possible to obtain energy due to the formation of helium from heavy hydrogen (deuterium) which is widely disseminated in nature. Every ton of ordinary water in nature contains as much as 200 gm of heavy water, whose molecules contain atoms of heavy hydrogen. The conditions needed for fusion of hydrogen into helium have thus far been created only in the hydrogen bomb. Scientists are working to produce the conditions for a decelerated controllable course of thermonuclear reaction without explosion, so as to learn to control this reaction and use it for purposes of power generation. The solution of this most difficult and challenging task will increase the resources of energy at the disposal of man by hundreds of thousands of times.

The cost of nuclear fuel is still high but is decreasing gradually from year to year. Today, it is only in rare cases that nuclear fuel is cheaper and more desirable to use than chemical fuel, but as nuclear power generation and the atomic industry develop further, the cost of nuclear fuel will become considerably lower than that of chemical fuels.

The wide utilization of atomic energy in industry, transport, and all branches of the national economy is one of the most difficult, but at the same time most lofty and noteworthy undertaking of contemporary science and technology.

First Conception of Atomic Aircraft Engines

The first thoughts as to the possibility of wide-scale use of atomic energy begin to appear even before the discovery of nuclear fission chain reaction. For example, as early as January 1935, the journal "Tekhnika Molodezhi" (Technics for Youth) carried an article by O.Petrovskiy, which examined the problem of using atomic energy in the national economy, this being the energy obtained by fusion of helium nuclei from hydrogen nuclei.

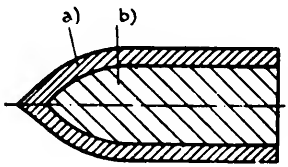

Fig.6 - Schematic Layout of a Hypothetical Nuclear Ram-Jet Engine
a) Reflector; b) Nuclear fuel

The practical introduction of atomic energy into the national economy was begun by the Soviet Union where the world's first atomic electric power plant was erected which has been working successfully since the summer of 1954. Then the question was posed, and has since been successfully solved, of developing atomic power plants for sea-going surface and submarine vessels. In the Soviet Union, a powerful atomic ice-breaker is under construction, and in the United States the first submarines with atomic engines have been tested.

The problem of using atomic energy in aircraft engines has proved to be one of

the most difficult to realize from the point of view of engineering. This problem is complex primarily because of the fact that an aircraft presents exceedingly rigid specifications with respect to engine weight, engine power, and absolute reliability in operation. Let us evaluate the probable future trend in the application of atomic energy to aircraft engines.

At first glance, it would seem that the simplest atomic aircraft engine would be one making use of the direct reaction of "fragments" resulting from the fission of heavy nuclei. Such an engine would simply be a lump of atomic fuel, encased in a container which reflects neutrons (Fig.6). The fission products of the nuclear fuel in this case would move only in the one open direction, thus creating thrust due to reactive forces. This simple design of an atomic rocket entine comprises fundamental contradictions, which necessarily render it unrealizable. Only a very thin surface layer is capable of radiating decomposition products into space. The fission reaction has to take place throughout the entire mass of fuel, and heat will be liberated throughout this entire volume. This creates instantaneous heating, melts the nuclear fuel, and converts it into vapor. In other words, this hypothetical engine would necessarily explode instantaneously. It is impossible to conduct a chain reaction only in the thin surface layer.

Is it conceivable to convert atomic energy directly into electric power and then make use of electric motors rotated by propellers?

Direct conversion of atomic energy into electricity is possible with the aid of an atomic electric generator or atomic battery. This battery or cell (Fig.7) is arranged as follows:

A spherical metal shell constituting an electrode of the atomic cell contains a second spherical electrode, coated with a thin layer of radioactive substance which emits beta particles. The air is exhausted from such a device. The internal electrode emitting beta particles of negative electric charge, is given a positive charge. The outer shell, on which the beta particles collect, is given a negative

charge.

Such an atomic battery would be able to yield high-voltage currents, but the current strength would be very small. This is due to the fact that the charge is transmitted to the outer shell only by the beta particles emitted by a thin surface layer of radioactive substance.

An atomic electric cell might also be built on the basis of utilizing artificial radioactive isotopes in combination with certain semiconductors. However, such "batteries" would also be so weak in power as to make their use for feeding of electric motors impossible.

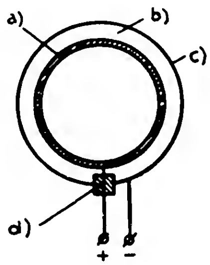

Fig.7 - Diagram of "Atomic Electric Generator" (Battery)
a) Nuclear fuel; b) Evacuated space; c) Shell; d) Insulator

Thus, direct conversion of atomic energy into electric energy cannot be employed today in power plants.

The reaction of the fission of heavy nuclei is accompanied, as we know, by the liberation of large amounts of heat. The question arises as to whether atomic energy cannot be utilized in a heat engine of some kind?

Let us take, for example, an internal combustion engine and instead of the fuel mixture let us charge a gaseous nuclear fuel of some kind into a cylinder. The engine must be so designed that, during the compression process, the density of the gaseous nuclear fuel is greatly increased and a nuclear chain reaction sets in. During the nuclear reaction, the emitted heat would be many times greater than that obtainable by the combustion of gasoline, so that such an engine would be much more powerful. However, an engine of this type is unrealizable since, in order for nuclear fuel to undergo a chain reaction in the gaseous form, even when compressed, an engine of colossal dimensions would be re-

quired.

Perhaps then solid nuclear fuel might be used in a two-cycle engine? To do this, a lump of nuclear fuel would be placed in the cylinder head, and another on the piston. When the piston reaches top dead center, the two lumps would approach so closely that a nuclear reaction would be initiated. The heat liberated would heat the air in the cylinder, thus starting the power stroke of the piston. In actuality, however, such an engine would explode the moment it is started. In fact, the atom bomb is designed in exactly this manner. Two pieces of the charge of uranium^{235} are brought together, with the result that a charge of uranium^{235} having greater-than-critical mass is produced, and a chain nuclear fission reaction results, causing an explosion.

Many similar fantastic schemes could be listed. Nevertheless we were justified in centering attention on heat engines, in view of the fact that more than 80% of the energy in the fission reaction is liberated in the form of heat.

Let us recall what an ordinary power plant for transport purposes comprises. Such a plant includes, as we know, an engine, a transmission, and a propulsive device. Within the engine, liberation of heat energy from the fuel and its conversion into mechanical energy takes place. These two processes may occur in a single system, as in an internal combustion engine, or in separate units as in a steam engine. The propulsive unit is the device that does the work of thrust created by the mechanical energy received from the engine. The wheels are the propulsive unit of an automobile; the propeller serves that function in an aircraft. The transmission transmits the energy from the engine to the propulsive device.

These three basic parts must by necessity be present also in an atomic power plant (Fig.8). Here the emission of heat occurs in a nuclear reactor as a result of the "combustion" of nuclear fuel as the nuclei undergo fission. In order to dissipate the heat from the reactor, it is honeycombed with channels through which a heat-transfer agent is propelled by pump. The heat-transfer agent may be either

fused metals of low melting point, gases (helium, nitrogen, carbon dioxide) or else ordinary or heavy water under high pressure. The heat-transfer agent, heated in the reactor as it passes through the heat exchanger, yields part of its heat energy to the substance actuating the engine and is returned to the reactor by a pump. Thus,

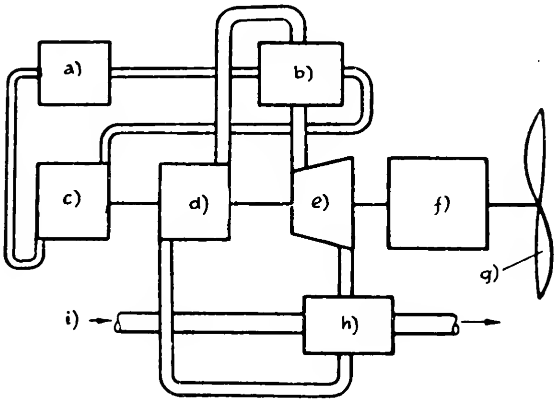

Fig.8 - Possible Schematic Layout of Aircraft Atomic Power Plant

a) Reactor; b) Heat exchanger; c) Pump for heat-transfer agent; d) Pump for working fluid; e) Turbine; f) Reduction gear; g) Propeller; h) Condenser; i) Coolant

circulating in a closed circuit formed by the reactor, the heat exchanger, the pump and the reactor, the transfer agent heats the substance actuating the engine, by way of atomic energy.

The engine used may either be a steam engine or a gas turbine. The actuating substance may be either water, mercury vapor, hydrogen, or helium, for example. Circulation of the actuating substance is by a pump, driven by the main or by an auxiliary turbine. For operation of the turbine, the exhausted steam must be dis-

charged into a condenser. In the condenser the steam is condensed into liquid and is recycled to the heat exchanger by the pump. The coolant medium on ship installations may be water of the surrounding medium, while in aircraft it may be the relative airflow. A condenser is necessary also if the working substance is a gas. Thus, we get the following circulating pattern for the working substance: heat exchanger - - turbine - condenser - pump - heat exchanger.

The turbine is connected to the driver by a transmission. In aircraft power plants mechanical transmissions are generally used. Shipboard power plants use electric transmissions, in which a number of electric motors connected to propellers are fed from a single powerful generator.

Aviation is the area in which atomic power plants may have broadest application. In addition to the above designs in which the turbine shaft is connected to a propeller over a reduction gear, the various types of aircraft engines in use today may be adapted for operation on atomic energy.

The reactor is a component of all atomic power plants. Many designs include heat exchangers. An examination of these vital components of atomic power plants is the subject of the next Chapter.

CHAPTER II

NUCLEAR REACTORS FOR AIRCRAFT POWER PLANTS

A nuclear reactor is a device within which a controllable chain reaction involving the fission of nuclei of fuel, accompanied by the conversion of atomic into thermal energy, takes place. The rapid progress in nuclear engineering and reactor design in recent years has led to the result that today nuclear reactors are being built successfully not only for stationary power plants, but for power plants of ships of various types. The first success in the design of nuclear reactors for aircraft power plants, no doubt, is imminent. According to reports in the foreign press, nuclear reactors for atomic aircraft engines, to reach flying speeds of the order of 900 km/hr for heavy aircraft, are already being ground-tested and flight-tested on experimental aircraft.

Main Features of Aircraft Nuclear Reactors and Their Specifications

To make it possible for an atomic aircraft to fly at high speed, an aircraft nuclear reactor must develop extremely high power. The power of a nuclear reactor, like that of any source of thermal energy, is measured by the amount of heat liberated in unit time. For example, if 1 kcal of heat is liberated per second of operation of a reactor, the power of the reactor will be 1 kcal/sec, or 3600 kcal/hr. In today's literature, the heating value of nuclear reactors is most frequently given in kilowatts (1 kw is equal to 860 kcal/hr).

Let us cite an example indicating the power requirement of an aircraft reactor.

Let us assume that an atomic aircraft weighs 150 tons and has a very advanced aerodynamic form. Calculations show that, to enable this aircraft to fly at the speed of sound at an altitude of 11 km, the nuclear reactor must have a power of about 300,000 kw. This is ten times as high as the power of the nuclear reactor in the first Soviet power plant, and approximately twice as large as the reactor of the Soviet atomic ice-breaker. In order for the atomic aircraft to fly at an altitude of 11 km, at 1.5 times the speed of sound, the power of its reactor would have to be approximately 900,000 kw.

The high power of an aircraft nuclear reactor has to be obtained within the smallest possible dimensions. If its dimensions are large, it will be difficult to house the reactor within the aircraft, especially if the aircraft is to remain fully streamlined. In addition, the larger the dimensions of the reactor, the greater will be the weight of the casings and shields needed to protect the crew and passengers of an atomic aircraft from the effects of the harmful radiations from the reactor. The exceedingly great weight of the radiation-shielding system is today one of the main obstacles to the design of an atomic aircraft useful for military and civil purposes.

The nuclear reactor for an aircraft power plant must weigh as little as possible. This requirement is particularly important for an atomic aircraft and is again based on the exceedingly great weight of the "dead" load - the radiation-shielding system.

An aircraft nuclear reactor must be a high-temperature reactor. The higher the temperature in the reactor, the smaller can be its size and weight and the smaller will be the size and weight required to yield a given power. An increase in the temperature results in an increase in efficiency of atomic engines of any type. This is very important, since the greater the efficiency, the less must be the power of the reactor in order to yield the required engine power. If it is borne in mind that the entire system of radiation shielding is dependent upon the

dimensions and size of the reactor, the major importance of achieving high temperatures will become obvious. Approximate calculations show that, in order to obtain the same flight characteristics for atomic aircraft as for chemical-fuel aircraft now in series production, the reactor surfaces must be heated to not less than 1000°C.

A nuclear reactor for aircraft must be highly reliable in operation. The requirement of reliability in an aircraft reactor for the desired term of service life is considerably stricter than for reactors in fixed positions. Unlike stationary reactors, the aircraft reactor must function normally no matter what its position in space. The functioning of the reactor must not be affected by inertia loads developing on changes in speed or direction of the aircraft.

General Design of a Nuclear Reactor and its Main Processes

The major processes in a nuclear reactor comprise a controllable fission chain reaction and dissipation of the heat generated by this reaction. The portion of the nuclear reactor in which the fission reaction occurs is called the active section or core. As a rule, the core contains the following materials: nuclear fuel, the moderator, the heat-transfer agent, material of the control or regulator devices, structural materials, i.e., materials needed to reinforce and fix the various design elements in their mutually correct position, to seal the heat-transfer ducts, to protect the nuclear fuel from oxidation, etc. The core is usually surrounded by a layer of substance that reflects neutrons.

Figure 9 shows one of the possible principal layouts of a nuclear reactor. Nuclear fuel, in the form of cylindrical rods contained in protective metal casings, is placed in grooves within the solid moderator. The generated heat is dissipated by a liquid heat-transfer agent, whose flow is shown by arrows in the diagram. Control of the nuclear fission reaction is by means of a control rod made of a material that is a good neutron absorber. The core of the reactor is shown by the broken

line in the drawing. The reaction of fission of heavy nuclei and all the attendent phenomena, such as liberation of heat, escape of secondary neutrons, etc., have been

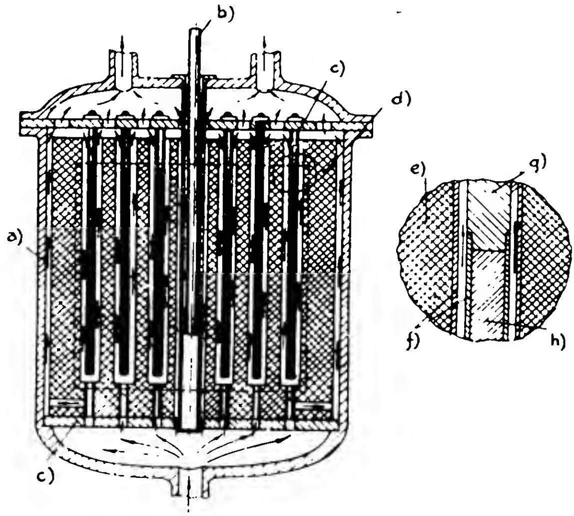

Fig.9 - Principal Schematic Layout of a Nuclear Reactor

a) Outer shell of reactor; b) Control or regulating rod; c) Retainer plate; d) Side reflector; e) Moderator; f) Protective shells; g) Hold-down rod; h) Rod of nuclear fuel

described in the preceding Chapter. Here we will deal with other processes in which neutrons participate.

Let us first examine the processes leading to variations in the kinetic energy of neutrons, i.e., the energy with which they move. The collision of neutrons with atomic nuclei of various materials, including nuclei of fuel, is not always accompanied by neutron capture. Often, the neutrons bounce off the nuclei, transferring to them a certain portion of their kinetic energy. As a result, the speed

of the neutrons decreases and, in addition, a change in the direction of motion takes place. This process has come to be called neutron scattering. The process of

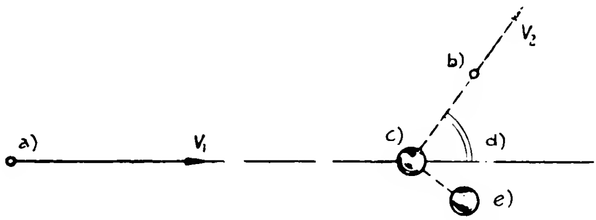

Fig.10 - Schematic Sketch of Neutron Scattering

a) Neutron before scattering; b) Neutron after scattering;

c) Nucleus before ecattering; d) Scattering angle; e) Nucleus after sc.

scattering is shown in schematic form in Fig.10. Here, V_1 is the speed of the neutron before collision with the nucleus, and V_2 is its speed after collision. At identical scattering angles, the magnitude of the kinetic energy released by the neutron depends upon the mass of the nucleus. The magnitude of the energy transmitted reaches a maximum when the mass of the neutron and the nucleus is identical. A case of this type may occur, for example, when a neutron collides with a hydrogen nucleus. Scattering, characterized by a considerable reduction in the energy of the neutron at each collision with the nucleus, is known as deceleration or moderation. The moderation of neutrons is a nuclear process artificially induced whenever a rapid reduction in neutron energy is required.

The secondary neutrons escaping on nuclear fission, possess a very high kinetic energy at their moment of "birth". The energy of the absolute majority of secondary neutrons lies within a range of 1 - 2 Mev corresponding to a speed of 14,000 - 20,000 km/sec. Neutrons of this velocity are called fast neutrons. In the course of the scattering process, particularly in the process of deceleration,

the kinetic energy of neutrons may decline to a level corresponding to the energy of thermal motion of the particles in the surrounding medium. Such neutrons are called slow or thermal. Their energy depends upon the temperature of the surrounding medium. For example, at a temperature of + 20°C, this energy is approximately 0.025 ev. The mean velocity of neutrons in this case is approximately 2 km/sec. At a temperature of + 700°C, the neutron energy is approximately 0.085 ev, and their velocity is 4 km/sec. All neutrons with a kinetic energy lower than that of the fast neutrons and higher than that of the thermal neutrons, are called intermediate neutrons.

The kinetic energy of the neutrons governs the relative number of neutrons in each generation participating in any given nuclear process, or as the saying goes, the probability that one or another process will occur.

Fission of the nuclei of uranium^{235}, uranium^{233}, and plutonium^{239} may be effected by thermal, intermediate, and fast neutrons. However, the probability of fission increases with decreasing energy of the neutrons because of the fact that, in this case, the probability that a neutron will be captured by the nucleus increases. These are the properties that make uranium^{235}, uranium^{233}, and plutonium^{239} highly efficient nuclear fuels.

Capture of the nuclei of uranium^{238} and thorium^{232} by thermal and intermediate neutrons does not result in fission. The fission of these nuclei is induced only by certain fast neutrons. For this reason, uranium^{238} and thorium^{232} cannot serve as nuclear fuels. The chain reaction in any nuclear reactor occurs primarily due to the fission of the nuclei of highly efficient fuels.

Now let us review briefly the processes, useless for the fission reaction itself but resulting in neutron loss. These processes include:

Capture of neutrons by fuel nuclei without subsequent fission;

Capture of neutrons by nuclei of all other materials used in the reactor;

Capture of neutrons by nuclei of fission products accumulated during regular

operation of the reactor.

All these processes can be categorized by the single concept: neutron absorption. Like scattering, the absorption of neutrons is inevitable, in view of the

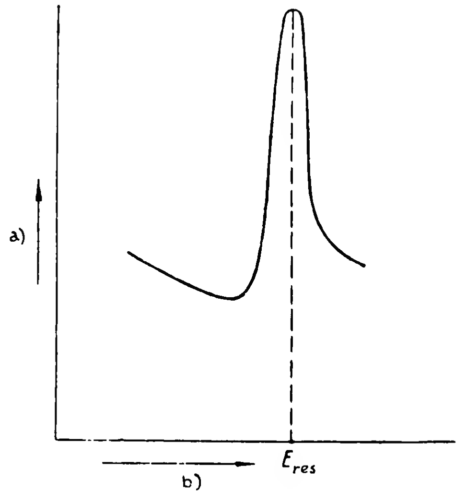

Fig.11 - Typical Graph of the Neutron Absorption Probability as a Function of the Energy of Their Motion

a) Absorption probability; b) Neutron energy

fact that all known materials absorb neutrons to some degree. At certain levels of neutron energies, which vary with the type of material, the absorption probability increases sharply. This phenomenon is known as resonance absorption. The phenomenon of resonance absorption is observed in a number of materials used in the manufacture of reactors, but it is most pronounced in the case of uranium^{238}.

Figure 11 gives a characteristic graph of the relationship between the probability of neutron absorption and their energy, for the case of uranium^{238}. The graph indicates that, at a neutron energy equal to E_{res}, neutrons are absorbed

particularly "avidly". The value of E_{res} is approximately 7 ev, corresponding to a neutron velocity of approximately 40 km/sec.

When a nuclear reactor is in operation, still another phenomenon resulting in a neutron loss is observed. A certain portion of the neutrons may escape from the bounds of the reactor, without undergoing fission. This phenomenon is called loss of neutrons by escape or neutron leakage. Neutron leakage is inevitable in any practical nuclear reactor.

The process of absorption and escape means that not nearly all neutrons generated during the fission process, actually participate in subsequent fissions. Therefore, the nuclear fission reaction can become a self-sustaining (chain) reaction only under certain circumstances.

The Critical State of a Nuclear Reactor

In order to make practical use of the atomic energy liberated during the fission of fuel nuclei, the prime requisite is that the fission reaction be self-sustaining. In other words, once having begun, it must continue spontaneously. The possibility of realizing such a reaction is based on the fact that, on splitting of each nucleus, two or three new (secondary) neutrons are produced; these are capable of inducing the fission of further nuclei. However, an attempt to realize this possibility is greatly hampered by the inevitable neutron loss: absorption and leakage. The minimum condition for realization of a self-sustaining fission reaction is that each generation of neutrons produced on nuclear fission gives rise to a new generation consisting of the same number as the preceding one. In other words, an identical number of neutrons participates in each successive act of fission, after the losses have been discounted. The condition of a reactor in which this requirement is met is termed the critical state.

The critical state is characterized by a neutron flux constant in time, by a constant number of fissions per second, and consequently by a constant quantity of

heat liberated per second, i.e., by a thermal capacity constant in time. The critical state is therefore also called the steady state, and the operating conditions of the reactor in this state are known as stationary or steady conditions. The amount of thermal power depends upon the number of fissions taking place in the reactor each second. It has been calculated that a power of one kilowatt represents 31,000 billion fissions per second.

What practical steps will have to be taken in order to attain the critical state?

Let us first consider the reaching of a critical state in a solid lump of highly effective nuclear fuel. We find that if the piece of fuel is exceedingly small, the nuclear reaction, after initiation, rapidly ceases. The main reason for this is the excessively large loss of neutrons by escape, due to the fact that, in a small lump, the collision probability with nuclei is very small. Neutron leakage occurs on the surface layer, while capture, resulting in fission, occurs throughout the entire volume of the lump. Consequently, neutron leakage may be reduced by reducing the ratio of surface to volume. For a given geometric form of the lump, this is attained by increasing its absolute dimensions, i.e., by the addition of nuclear fuel. As soon as dimensions of a certain size are reached, the leakage is reduced to the point that the same number of neutrons will participate in subsequent fission processes as in the preceding processes. This means that, in practice, the critical state in nuclear fuel is reached by bringing its quantity up to a certain definite size. The size and mass of a lump of nuclear fuel representing the critical state, are called the critical size and critical mass. Minimum critical mass of nuclear fuel will be obtained with lumps of spherical form, since a sphere represents the minimum ratio of surface to volume. For uranium^{235}, the critical mass of a spherical lump is approximately the mass weighing 1 kg.

In a practical nuclear reactor, the fuel is distributed more or less uniformly throughout the volume of the core. Loss of neutrons by escape, in this case, depends

not only on the quantity of nuclear fuel but also on the dimensions and geometric shape of the core. In addition to fuel, the core contains other materials necessarily participating in the scattering and absorption of neutrons. The ability of these materials to scatter and capture neutrons varies with variations in temperature.

The properties of these materials, the relative quantity of each in the core, and the relative position of each determines the mean velocity of the neutrons at which the overwhelming majority of nuclear fissions of the fuel takes place. This velocity is the basis on which reactors are classified into thermal, intermediate, and fast-neutron reactors.

As we see, the condition of a practical nuclear reactor depends upon a number of circumstances, but in practice the critical condition is reached by charging a specific amount of nuclear fuel into the core, in view of the fact that all the other conditions are usually present to begin with. For example, the type of reactor is selected in the light of its purpose and the properties of the nuclear fuel available. The dimensions of the core are based on the conditions required to attain the desired power and, consequently, the necessary heat transfer per unit time. The operating temperature is based on the properties of the materials used, etc.

Thus, in an atomic power plant, it is necessary to have an adequate quantity of nuclear fuel only to permit utilization of a portion thereof to liberate the enclosed energy. In other words, an atomic power plant is capable of functioning, other conditions being equal, only so long as the quantity of unused nuclear fuel remains above the critical level. Further consumption of fuel is simply impossible. When it is stated that an aircraft with an atomic engine will burn 500 - 600 gm of nuclear fuel in the course of a flight around the world, this does not mean that such a flight can be performed with only 500 - 600 gm of fuel aboard the aircraft. These 500 - 600 gm can be consumed only if they represent merely a small portion of the mass (weight) of the total fuel aboard the aircraft and in the reactor.

As we shall soon see, the quantity of nuclear fuel required to maintain a critical state, does not remain constant during operation of the reactor, and increases as the temperature increases and also as fission products accumulate. In the very best reactors now in operation and under construction, the critical weight of highly efficient nuclear fuel at the end of the period of operation is not less than 80% of the weight after the initial charge. This means that not more than 20% of the initial charge can be consumed in the course of operation. This is one of the peculiarities of an atomic power plant as compared with those using chemical fuels. In the latter, as we know, the entire available fuel can be completely consumed.

Enormous amounts of labor and materials are required to obtain highly efficient nuclear fuels. It is natural therefore that tremendous efforts have been made by scientists and engineers of all countries working in the field of nuclear energy and reactor design, with the object of finding means of reducing the critical weight (mass) of nuclear fuel.

Reduction in the critical weight is facilitated by all measures that tend to diminish the neutron loss. One of these measures is the use, in the manufacture of reactors, of materials that absorb as few neutrons as possible. The minimum critical weight is obtained when the moderator and heat-transfer agent is heavy water, while zirconium is used as the structural material. However, the use of these materials is not always possible. Specifically, to attain high operating temperatures, it is sometimes necessary to use fused metals as the heat-transfer agent, and heat-resistant nickel alloys as the structural materials. Since these materials have high neutron-absorbing properties, the quantity of such materials used within the core must be reduced in order to lower the critical weight of the fuel.

The critical weight of nuclear fuel may be reduced by making provision to have the neutrons leaving the core reflected back into that core. If the core of a reactor is surrounded by a scattering substance, it will act as a reflector, i.e., a portion of the neutrons leaking from the core will be returned to there. This

will result in a reduction in the loss of neutrons by leakage, and the critical state will be reached with a lower quantity of nuclear fuel than is the case when no reflector is used.

In selecting the material for the reflector, the following are the governing conditions: In the first place, the amount of neutrons returned is greater, the closer to the boundary of the core the point is located at which the scattering collisions of neutrons with nuclei from the reflector take place, and in the second place, the fewer the collisions resulting in neutron absorption. Consequently, in order to arrange for effective reflection, it is necessary to select a material for which the probability of neutron scattering would be as great as possible and the probability of absorption as small as possible. Heavy water is the best material for this purpose. Graphite, beryllium, ordinary water, zirconium, and certain other substances follow in order of diminishing the reflectivity.

Let us see what effect the thickness of a reflecting layer has on the process of reflection. Let us assume that we gradually increase the thickness of the reflector. The results are shown in the graph in Fig.12. The number of neutrons returned by the reflector into the core are laid off, on the vertical axis, while the thickness of the reflecting layer is plotted on the horizontal axis. The graph shows that, as the thickness of the reflector increases, the quantity of neutrons returned to the core also increases. The sharpest increase is produced by the layers closest to the core. The following layers, although they do return neutrons, do this to a lesser degree than the preceding ones. Finally, starting at some particular thickness, represented by the segment OA, the number of neutrons returned ceases to increase for all practical purposes. Any further increase in the thickness of the reflector is purposeless, since the bulk of the neutrons will be reflected or absorbed before the outer boundary of the reflector is reached. The thickness of the layer to which the reflection effect continues to increase substantially, is approximately as follows: 1.5 - 2.0 m for heavy water, 0.8 - 1.0 m

for graphite, and 0.45 - 0.5 m for beryllium.

When a reflector is used, there is an increase in the number of fissions of the nuclear fuel per second, immediately adjacent to the boundary of the core of the

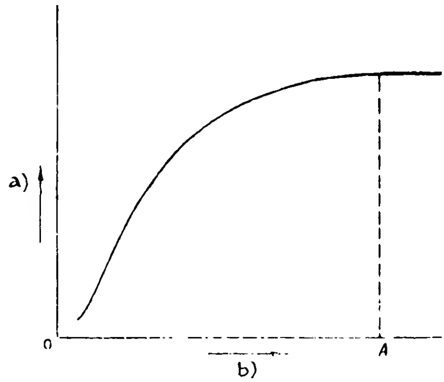

Fig.12 - Effect of Thickness of Reflecting Layer on the Process of Reflection

a) Number of neutrons returned to the core by the reflector;

b) Thickness of the reflecting layer

reactor. More efficient utilization of the peripheral zone makes it possible to obtain the desired quantity with a core of smaller dimensions than in a reactor not using a reflector. This is most important as far as aircraft reactors are concerned, in which the requirement of a reduction in dimensions of the core is of prime importance. It is true that the overall dimensions of the reactor are greater when a reflector is used than when it is not, but it must not be forgotten that the reflector, in any case, is an integral part of the shielding from the neutron stream. The thicker the reflector, the less will be the required thickness of the special shielding. In order for the reflector to form an effective portion of the

aircraft shielding system, it is preferable to use a material that slows neutrons effectively. The decelerated neutrons moving past the reflector will be completely absorbed in a relatively thin layer of special protective shielding.

In the nuclear reactors of modern stationary and sea-going power plants, water and graphite are the materials most often used for the reflector, since they are cheapest and adequately efficient. In high-temperature aircraft reactors, the use of water is impossible because of its low boiling point. Therefore, graphite is the only cheap material remaining. A reactor with reflector will have the smallest dimensions if metallic beryllium is used as reflector. Beryllium has a relatively high melting point (1315°C), is light, and inert to neutron irradiation. A disadvantage of beryllium is its high price.

Unstable Operating Conditions of Nuclear Reactors

A steady state, in which the neutron flux and the capacity of the reactor remain constant in time, is observed when the reactor is in the critical state by the fact that the neutron multiplication constant K is equal to unity. The multiplication constant K is the ratio of the number of neutrons undergoing fission in a given generation to the number of neutrons that have fissioned in the preceding generation. If the multiplier deviates from unity for any reason, the neutron flux, the number of fissions per second, and the power of the reactor will also vary with time, increasing or decreasing accordingly. The operating conditions of a reactor in which its power changes with time are called nonstationary or unstable.

The multiplication constant is equal to unity when the amount of nuclear fuel within the reactor core is exactly equal to the critical quantity for the given operating conditions. A change in the multiplication constant occurs when this equality is violated.

If the weight of the nuclear fuel within the core is less than critical, the multiplication constant is less than unity. This condition is called subcritical,

and the power of the reactor will drop steadily so long as this is the case. In actuality, the reactor is converted to subcritical conditions when it is necessary to reduce the generated power or to shut down the reactor.

If the reactor contains more than the critical amount of nuclear fuel, the multiplication constant will be greater than unity. This is called the supercritical state of the reactor and is characterized by a constant increase in power, in view of the fact that the fission reaction now becomes a virtual avalanche. In actual operation, a reactor is placed in the supercritical state for the purpose of "racing it", i.e., to increase its power. A special case of racing or "riding up" is the starting of a nuclear reactor.

Thus far we have spoken of fission reactions, without discussing how they are initiated. Let us make good this omission. It will be found that, in any nuclear reaction, there is always a certain number of free or, as they are called, stray neutrons. A percentage of these are generated as the result of the spontaneous fission of fuel nuclei*, another portion is knocked out of the nuclei by particles of cosmic radiation. Although the number of stray neutrons is small, it is quite sufficient to start a chain fission reaction. In order for an inoperative reactor to "come alive", it is enough to bring the multiplication constant to a quantity slightly larger than unity.

A most important characteristic of unstable operating conditions is the time rate of change in power. It is most important to know the rate of increase in power in the supercritical state of the reactor. An excessively rapid progression of the reaction creates difficulties in controlling it. Modern systems of automatic control, no matter how quick-acting they may be, require a certain amount of

* The phenomenon of spontaneous fission of the uranium nucleus was discovered by the Soviet scientists, G.N.Flerov and K.A.Petrzhak. They showed that in one gram of natural uranium there occur on the average 23 spontaneous fissions per hour.

time to function. It may happen that, during this time, the liberation of heat in the reactor will greatly exceed the removal of heat, so that the reactor will melt. An excessively slow increase in power is also not always desirable, particularly in an aircraft reactor. An aircraft reactor must have good pickup, i.e., it must be able to change rapidly from one steady state to another.

The rate of increase in power is greater, the greater the so-called excess reactivity or the reactivity of the reactor. By excess reactivity k_{ex} we mean the degree to which the multiplication constant is greater than unity

$$K_{ex} = K - 1.$$

For example, if the multiplication constant is 1.05, the excess reactivity is 0.05. The amount of excess reactivity indicates the relative increase in the number of neutrons fissioning from one generation to the next. In the given case, this increase is 5%.

The rate of increase in power also depends on the type of nuclear reactor. In a fast-neutron reactor, it is greater than in a thermal-neutron reactor. To anticipate the discussion for a moment, it should be mentioned here that different types of reactors will not always exhibit a significant difference in rate of acceleration.

Let us define the rate at which the power of a reactor increases. Let us assume that we are dealing with a thermal-neutron reactor in the critical state and developing some given power. Let us assume that we have effected a sudden increase in the multiplication constant to K = 1.1, i.e., that we have introduced a reactivity $k_{ex} = 0.1$. Calculations show that, at this reactivity, the power of the reactor will increase in two thousandths of a second by a factor of 2.7; in one hundredth of a second it will increase by 1500 times, and in two hundredths of a second by approximately 20,000 times. A breakdown is therefore almost inevitable. In a fast-neutron reactor, at $k_{ex} = 0.1$, the power increases approximately 150,000 times

in one millionth of a second. This rate of evolution of a chain fission reaction is close to that occurring in an atomic explosion.

The rapid increase in the power of a reactor of any type is explained by the fact that the velocity of motion, even of thermal neutrons, is sufficiently large for this to occur, while the distance traversed by the neutrons before collision with nuclei is small. As a result, very small intervals of time elapse from the instant of generation of a neutron to the instant when the neutron is captured by a nucleus of the fuel. Under these conditions, the process of fission rapidly encompasses an enormous number of nuclei.

The rate of acceleration may be reduced by lowering the reactivity, but even if this rate is reduced to 0.01, it still is not possible to control a nuclear reactor. As soon as the reactivity drops below 0.01, the picture changes sharply. The point is that, during the exceedingly brief period of time required for the act of fission, only 99% of the total number of secondary neutrons escape. These are known as prompt neutrons. The remaining neutrons (approximately 1%) appear in groups, with a delay of up to 80 sec. These are the so-called delayed neutrons, which are emitted in "fragments" of the fissioned nuclei, as they undergo radioactive decay. If the degree of radioactivity is equal to or smaller than the percentage of delayed neutrons, then an increase in the number of fissions in each generation will result only due to the delayed neutrons. In this case, the rate of increase in power is determined chiefly by the time during which the delayed neutrons appear. The time required for the neutrons to travel from the instant of their generation to the instant of their encounter with the nuclei of the fuel is not a significant factor, since this time is exceedingly short relative to the time lag of the neutrons. As a consequence, the rate at which the reactor is accelerated will be considerably less, although for reactors of various types it is approximately identical at identical reactivity.

More exactly, the percentage of delayed neutrons is given by the figure 0.00755.

Therefore, in order to guarantee safe operation during the startup or power increase of the reactor, the reactivity introduced must be less than 0.00755 and comprise approximately 0.005 - 0.006. At this reactivity, a thermal-neutron reactor will require approximately 6 sec to increase its power by a factor of 2.7, and will require 30 sec to increase it by 500 times. The increase in the power of a fast-neutron

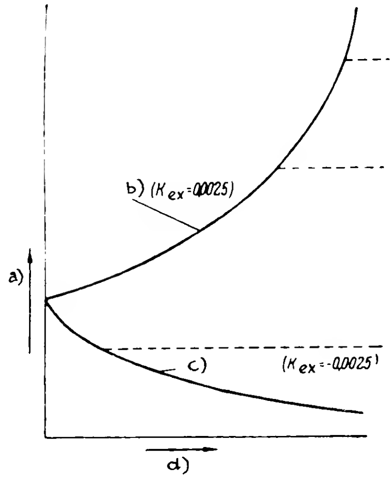

Fig.13 - Time Rate of Change in the Power of a Reactor, when "Raced" or Shut Down

a) Reactor power; b) "Racing" (k_{ex} = 0.0025);
c) Shutdown (k_{ex} = - 0.0025); d) Time

reactor takes place at approximately the same rate. Reliable regulation of a chain reaction is completely assured at this rate.

Along with the increase in the time required to raise the power, the presence of delayed neutrons results in a decline of the rate of reduction of power when a reactor is in the subcritical state. In practice, the power cannot be reduced more

rapidly than is "permitted" by the delayed neutrons. Figure 13 illustrates the changes in power as a function of time when a reactor is accelerated or shut down at a given steady state. The excess reactivity, in absolute value, is 0.0025. The broken line shows a number of new steady states that can be attained as a result of increasing or diminishing the initial assigned power.

What are the causes of the variations in the reactivity of a reactor?

In the first place, the reactivity may be changed at the discretion of the person controlling the reactor. This includes the actions of automatic devices which, set up by man, will substitute for his action. One of these actions is the shifting of the control rod made of a material that is highly neutron-absorbent. When the rod is pushed into the core, the neutron loss by absorption increases. If, prior to the introduction of the rod, the reactor had been in the critical state, it will become subcritical after introduction. Under the new conditions, the amount of nuclear fuel in the core will be insufficient to sustain a critical state. When the rod is withdrawn from the core, on the other hand, the neutron losses decrease and the reactivity increases.

Secondly, when a nuclear reactor is in operation, spontaneous changes in reactivity may occur. One of the causes of this is the "combustion" of the nuclear fuel, with the result that its amount in the core drops and the reactivity is reduced. In order to prevent spontaneous shutdown of the reactor, it is necessary either to provide for a constant refueling or in some way to reduce neutron loss during operation of the reactor.

Another reason for the reduction in reactivity is the accumulation of reaction fission products that are strong neutron absorbers, or as the saying goes, reactor poisoning. Poisoning results in an increase in the loss of neutrons by absorption and consequently in an increase in the required critical weight. In terms of any specific reactor, the degree of drop in reactivity due to poisoning is greater, the greater the power level at which the reactor has been operating. The poisoning ef-

fect is most noticeable in reactors using thermal neutrons, insofar as thermal neutrons are avidly absorbed by the nuclei of certain fission products.

Spontaneous changes in the reactivity of a reactor also occur when the core temperature is changed. An increase in temperature usually results in a decrease in reactivity. When overheating occurs, the density of all materials declines, i.e., there is an increase in the distance between the atomic nuclei. This leads to a reduction in the collision probability between neutrons and nuclei, to a decrease in the number of fissions, and an increase in neutron leakage. When the temperature is decreased, the nature of the phenomena is the opposite, and the reactivity of the reactor increases.

The fact that such a relationship exists between reactivity and temperature has a positive effect on the functioning of a reactor and makes it easier to control. Let us assume that, for some reason, the reactor has spontaneously entered a supercritical state. This causes the number of fissions per unit time to increase, thus also increasing the liberation of heat. Consequently, the temperature of the core increases. However, when the temperature increases, the reactivity begins to drop with the result that the further development of a chain reaction is somewhat slowed. In some cases, when the accidental fluctuation in the reactivity of a reactor is small, the reactor may spontaneously, without the intervention of a control system, return to its previous power level. The thermal effect is most marked in reactors using thermal neutrons, particularly if uranium^{238} is a constituent of the fuel.

As temperature increases, there is an increase in the kinetic energy of the thermal neutrons. As a result, the probability of fission of nuclei of highly efficient fuels becomes less, while the probability of absorption by the nuclei of uranium^{238} increases. In order to provide for maintenance of a steady state during temperature fluctuations, some means of compensating the change in reactivity, occurring under these conditions must be provided.

Controlling the Nuclear Reactor

Control of a nuclear reactor consists of sustaining the desired power or changing it in a desired direction. To control a reactor, provision must be made for varying the reactivity of the reactor. This problem may be solved by the following methods:

By varying the amount of nuclear fuel in the core or by changing the mutual arrangement of the components;

By changing the quantity of moderator;

By changing the effective area or thickness of the reflectors;

By changing the position of external neutron sources relative to the core;

By changing the position of the regulating (controlling) means, made of materials that are good neutron absorbers.

At present, the last of the methods listed has come into wide use as being the simplest in terms of design and as being adequately effective, particularly for reactors using thermal neutrons. The controlling means most often take the form of cylindrical rods. The material used for these rods may be cadmium, boron, boron carbide, or boron steel. Cadmium is the most avid neutron absorber but has a rather low melting point (about 321°C), and is therefore less frequently used. An advantage of boron, aside from its high absorptivity and high melting point, is the virtually complete absence of induced radioactivity due to absorption of neutrons. As mentioned before, the change in reactivity obtained by means of the control rods, is due to change in the loss of neutrons of each generation by absorption. Introduction of the rods into the core reduces the reactivity of the reactor, while withdrawal of the rods increases it.

The reactor core is so designed that the weight of the initial charge of nuclear fuel will exceed the minimum critical weight. A portion of the excess fuel represents a reserve against consumption, i.e., it may be expended in producing thermal energy. The other portion, the so-called reserve against poisoning and

temperature effect, is not consumed in operating the reactor. This portion of the fuel is used to sustain the critical condition in the reactor during accumulation of fission products and increase in temperature.

The excess or reserve reactivity due to the fact that the amount of nuclear fuel present is greater than the minimum critical amount, is compensated by the control rods and may be eliminated if necessary. The degree of reactivity freed when the rod is completely withdrawn from the core, is known as the compensating capacity of the control rod. The compensating capacity depends upon the material of the rod, its diameter, and its position in the core. Rods passing through the center of the core have the greatest compensating capacity. The total compensating capacity of the control rods of a reactor must exceed the initial reserve reactivity.

Let us next discuss the principal operating conditions of a control system. In order to proceed from one steady state to another in which the power is greater, the rod must be withdrawn from the core. When this is done, the power of the reactor begins to increase. As soon as a desired power level has been reached, the rod must be returned to a position corresponding to zero reactivity. If the change-over to the new operating conditions is completed within a very short period of time and is not accompanied by significant changes in the temperature of the core, the rods will be returned almost to their initial position.

In order to reduce the power level, the rods must be inserted deep into the core and, after the desired level has been reached, be returned to their initial position. The degree of displacement of the rods determines the degree of reactivity, i.e., the time rate of change in power. Compensation for the reduction in reactivity due to consumption of the fuel and poisoning of the reactor, is accomplished by gradual withdrawal of the control rods from the core.

Maintenance of the assigned operating conditions of the reactor is automatic. A deviation of the power of the reactor from the required level causes a change in the neutron flux in the reactor, which is immediately recorded by ionization

counters mounted around the core. The signals from these counters, magnified by means of electronic systems, are transmitted to the electric drives which effect the necessary change in the position of the control rods. In modern nuclear reactors, the assigned power is maintained with an accuracy to within one tenth of a percent.

In addition to the rods controlling the reactor in normal operation, emergency protective rods must be provided. Their purpose is to stop the nuclear fission reaction under conditions in which even the briefest delay in shutdown might cause breakdown of the reactor. Such conditions include:

Very rapid increase in power during startup;

Rise in temperature of the core above the permissible level;

Drop in pressure of the heat-transfer agent, indicating a leak in the system or failure of the pump; and several other cases.

The emergency rods usually are introduced automatically. In the majority of reactors for stationary installations, the emergency rods are vertical. If necessary, they are "dumped" into the core. The speed of free fall of the emergency rods is sufficient to stop the chain reaction in time. In aircraft reactors, the emergency rods must necessarily be provided with an independent drive. This is necessary to assure rapid insertion no matter what the conditions of flight. The simplest, lightest, and most reliable drives are spring-actuated or use compressed gas or a powder charge.

Types of Nuclear Reactors

Above we have already indicated some specific features of various types of reactors. In the following, we will discuss other peculiarities and will attempt to draw certain conclusions as to the applicability of various reactors for aircraft power plants.

Thermal-Neutron Reactors. The development of nuclear reactors for use with thermal neutrons, was triggered primarily by the attempt to use natural and low-

enriched uranium as the nuclear fuel. The point is that it is impossible to cause a chain reaction in a lump of natural uranium, even if the size of the piece were increased to infinity. This is because of the low probability of fission of uranium^{235} by high-energy neutrons and the exceedingly high losses of neutrons due to resonance absorption by the nuclei of uranium^{238}.

The fission reaction in natural uranium can become a chain reaction only if thermal neutrons are used. The probability of capture of thermal neutrons by the neutrons of highly efficient fuels, and resultant fission, is much higher. At the same time, there is a reduction in loss of neutrons by absorption since a rapid drop in energy results in a considerable increase in the number of neutrons which "jump" regions of resonant energies.

In order to decelerate the neutrons, a neutron moderator is placed in the reactor core. The moderator is made of a material comprising chemical elements with the lightest possible atomic nuclei. These are the elements at the very beginning of Mendeleyev's periodic system. The lighter the nucleus of the moderator, the more energy is lost by the colliding neutrons and, consequently, the greater is the probability of skipping the energy levels at which resonance absorption into uranium^{238} takes place.

However, a pronounced reduction in the energy of the neutrons during a single collision is of no value if the collisions are very rare. In this case, the loss of neutrons by leakage will be very great.

Moreover, the nucleus of the moderator must not be a powerful neutron absorber. Thus, the moderator must consist of light nuclei, having the greatest scattering probability for neutrons and the least absorption probability. Only a few good moderators are known: heavy water, graphite, beryllium, beryllium oxide (BeO). In high-temperature nuclear aircraft reactors, it is apparently possible to use only graphite, beryllium and its oxide.

The use of natural and even low-enriched uranium in nuclear reactors for atomic

aircraft does not seem possible thus far, since this would require reactors of excessive dimensions and weight. The simplest calculations show that, at present, the designing of an atomic aircraft flying at a speed somewhat higher than the speed of sound is possible only if the fuel used is uranium enriched at least by 50%. The design of aircraft with atomic engines for still higher supersonic speeds will require a greater degree of enrichment.

Nuclear reactors for thermal neutrons have one great advantage over all other types of reactors - minimum critical weight for the nuclear fuel. When the fuel is diluted by the moderator, there is a decrease in loss of neutrons by leakage, because of the fact that, the lower the energy of the neutrons, the greater will be the probability of their capture by the fuel nuclei. On the other hand, there is an increase in the loss of neutrons by absorption by the nuclei of the moderator. Up to a given degree of dilution, which is called optimum, the saving in neutrons due to a reduction in leakage is greater than the loss by absorption, so that the critical weight of the nuclear fuel decreases. At the optimum ratio of the amount of fuel to that of moderator, the critical weight of a given fuel will reach a minimum. On further dilution, this weight increases because since reduction in leakage is insufficient to compensate for the reduction of neutrons due to absorption.

Figure 14 gives a graph showing the change in the critical weight of nuclear fuel and the critical dimensions of the core of a reactor, on gradual dilution of the fuel by a moderator. The solid line is the change in the critical weight of the fuel (P_{cr}), while the broken line represents the change in the critical size of the core (R_{cr}). We see that the critical weight of nuclear fuel (P_{min}) is considerably less than the critical weight of the undiluted fuel (P_o). True, the size of the core in this case is greater than the deficiency in moderator.

The use of thermal-neutron reactors in aviation is advantageous in cases in which the greatest possible area of heating surface of the core is required. In practice, this occurs in the design of ram-jet and turbojet atomic aircraft engines,

with direct heating of the air stream in the reactor. The emission of heat into the air stream is characterized by a comparatively low coefficient of heat transfer, of

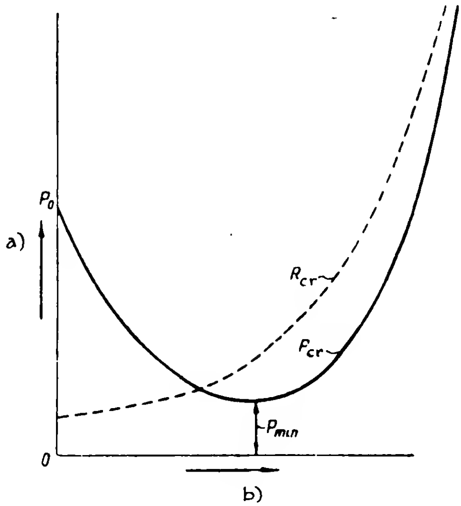

Fig.14 - Variations in the Critical Weight of Nuclear Fuel and Critical Dimensions of the Core of a Nuclear Reactor as a Function of the Ratio of Fuel and Moderator Amounts

a) Critical weight of nuclear fuel and critical dimensions of core;

b) Percentage content of moderator in mixture with fuel

not more than 600 - 800 $\frac{\text{kcal}}{\text{m}^2/\text{hr} \cdot \text{deg}}$. Therefore, the area of heating surface is usually inadequate, without dilution of fuel. The use of a moderator results in an increase in heating surface.

The mutual arrangement of the fuel and the moderator in a thermal-neutron reactor may vary. If the nuclear fuel is uniformly distributed throughout the moderator, dissolved, or intermixed, the reactor is known as a homogeneous reactor. A

homogeneous active mass may be solid, liquid, or gaseous. A liquid mass, in turn, may be a solution of fuel in a moderator, or a suspension, i.e., a uniform distribution of solid fuel particles in a liquid moderator. A general advantage of homogeneous reactors is the simplicity of design of their cores.

Actually, this is the simple and reliable design applied in the boiling homogeneous reactor designed by the Academy of Sciences of the USSR. The design of this reactor is shown in Fig.15. The active mass, consisting of a solution of uranium salts in heavy water, is encased in a metal tank of spherical shape. The heat liberated as a result of the fission reaction causes the liquid to heat up and boil. High-pressure steam is tapped for use in steam-powered devices. The condensate from the steam-powered device is returned to the reactor by pump. A fundamental shortcoming of homogeneous reactors is the comparatively high probability of absorption of neutrons by nuclei of uranium^{238}. Therefore, the realization of a self-sustaining fission reaction, using natural uranium as the fuel, is possible only if a better moderator than heavy water is used.

If nuclear fuel in the form of separate and rather large rods or blocks is placed in an undiluted moderator, the device is called a heterogeneous reactor. Heterogeneous means nonidentical. The distance between the blocks is so selected that the energy of the neutrons exceeds the resonance levels in the spaces between the blocks. One of the possible designs of heterogeneous reactors has already been described and was shown in Fig.9. The design of the core of such a reactor is more complicated than that of a homogeneous reactor, but the limitations of the latter, with respect to possible moderator materials, do not exist here. In modern reactors of stationary power plants, graphite and ordinary water are in wide use as moderators. These materials are considerably cheaper than heavy water.

The nuclear reactor of the first Soviet power plant is a heterogeneous reactor using thermal neutrons. Its core is a cylinder 1.5 m in diameter and 1.7 m in height. Graphite is used as the moderator and reflector. The heat-transfer agent

is ordinary water. The nuclear fuel is metallic uranium enriched by its isotope 235. The degree of enrichment is 5%. The initial fuel charge is about 550 kg.

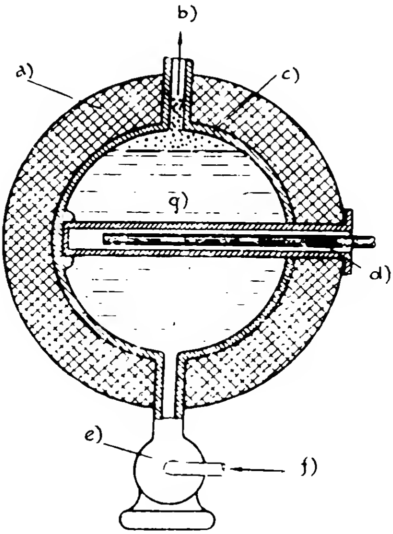

Fig.15 - Schematic Diagram of Boiling Homogeneous Nuclear Reactor

a) Reflector; b) To steam engine; c) Pressure vessel; d) Control rod; e) Pump; f) From steam engine; g) Solution of $uranium^{235}$ salt in heavy water

Of this, about 27 kg is $uranium^{235}$. The combustion reserve is approximately 3.5 kg. Approximately the same amount is provided as a reserve against poisoning and temperature effect. Consequently, the excess of nuclear fuel over the minimum critical weight is about 7 kg. The initial reactivity reserve is 0.13. In order to compensate for excess reactivity and for inaccurate control of the reactor, 18 com-

pensating rods of boron carbide are provided in the core. Another four rods are provided for precise automatic control, plus two emergency protective rods for stopping the reactor under emergency conditions. The overall compensating capacity of the regulating rods is about 0.16. The compensating capacity of the emergency rods is 0.02. The thermal capacity of the reactor is estimated as 30,000 kw.

The advantage of heterogeneous reactors in that they reduce resonance absorption within uranium^{238} is not significant for aircraft reactors. The selection of some system of placing the fuel and the moderator in the aircraft reactor is based primarily on the requirement of obtaining a simple reactor, reliable in operation. Taken into consideration here are the type of aircraft engine to be driven by the reactor, the high thermal load of an aircraft reactor, the possibilities of uneven heating and fluctuations in temperature, the need to assure reliable dissipation of heat no matter what the position of the reactor in space, and a number of other factors.

Several authors in other countries have proposed using so-called porous homogeneous reactors in rocket-type atomic aircraft engines. The core of such a reactor is an assembly of conical tubes extruded from a homogeneous mixture of highly efficient nuclear fuel and powdered graphite. The tube walls are honeycombed with an enormous number of fine channels, through which a fluid or gaseous heat-transfer agent flows. This agent functions at the same time as the working substance of the rocket. The design for such a reactor, housed in a rocket, is shown in Fig.16. The porous reactor has the following important advantages: a large surface area for heating, combined with comparatively small dimensions of the core and a possibility of reaching working temperatures above the melting point of the nuclear fuel. However, a porous reactor in the form in which it is proposed has the following important disadvantages which constitute an obstacle to its practical application, specifically as a high-temperature reactor: A highly complex technology is required for the manufacture of the solid homogeneous mixtures, and the probability of de-

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struction of the solid mixture due to irregularity in the heating of the various segments and fluctuations in temperature is great. In addition, clogging of the

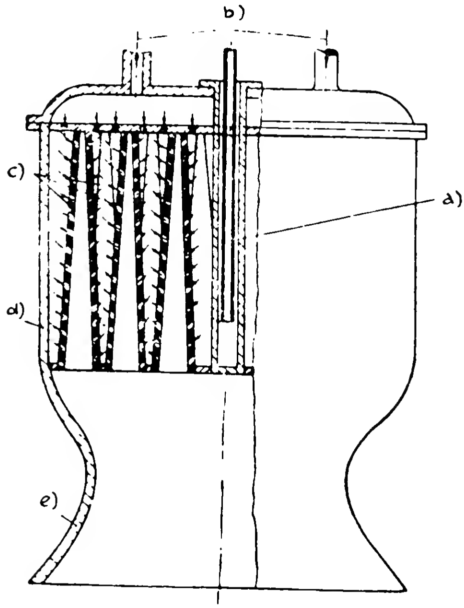

Fig.16 - Design of an Atomic Rocket Aircraft Engine with a Porous Homogeneous Uranium-Graphite Reactor

a) Control rod; b) Delivery of heat-transfer agent from pump; c) Porous active mass; d) Shell; e) Jet nozzle

capillary channels by particles of the active mass and by "fragments" of the fissioned nuclei may occur during operation of the reactor. Clogging of the channels over even a short distance results in local overheating and, in the long run, in breakdown of the entire reactor.

The use, in thermal-neutron aircraft reactors, of a homogeneous active mass consisting of an alloy of metallic uranium and metallic beryllium offers good possibilities. The active mass is housed in thin-walled cans of heat-resistant material, which may be cylindrical or tubular (with double walls), or else spherical, etc. A portion of the active mass with its can is called the heat-producing element or fuel element. The cans protect the mass from oxidation and shield the heat-transfer agent from contamination by the radioactive fission products, and also impart mechanical strength and rigidity to the heat-producing elements at high temperatures. The fuel assembly, with the individual elements attached to each other and to the shell of the reactor, forms the structural essentials of the core.

Figure 17 shows one of the possible design variants of a core using uranium-beryllium alloy. The design of the heat-producing elements and the method of combining them into a single whole is readily understood from the drawing. A reactor of this type may be used to heat a flow of air passing through its axis or a gaseous intermediate heat-transfer agent. If the material of the containers holding the heat-producing elements permits this, the working temperature can be raised above the melting point of the active mass.

Still another variant of a possible design for the core of a uranium-beryllium reactor, intended for direct heating of the airflow through the engine, is presented in Fig.18. Here the uranium-beryllium alloy is housed in a hermetically sealed cavity, penetrated by a large number of thin-walled metal tubes. The active mass occupies the space between the tubes. The air to be heated moves along the tubes to the reactor. To obtain a hermetic seal of the front and rear surfaces of the reactor, the ends of the tubes are connected by welding. Usually the core of this type of reactor consists of a number of sections. The edges of one of the sections are shown as a broken line in the left half of the drawing. Such a sectional design greatly simplifies the engineering required in making and assembling the core.

In order to lower the neutron leakage, a solid outside reflector is provided.

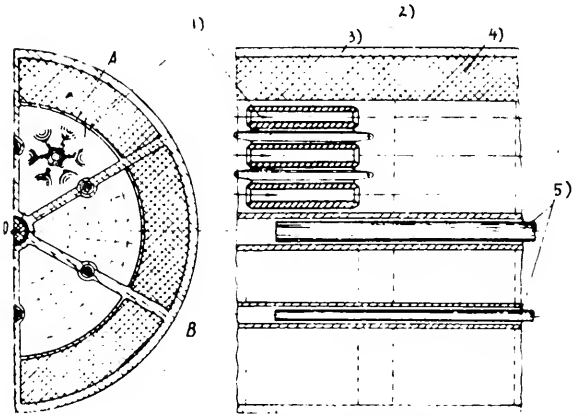

Fig.17 - Design of a Uranium-Beryllium Homogeneous Reactor, Intended for the Heating of a Gaseous Intermediate Heat-Transfer Agent

1) Heat-producing elements; 2) Section through AOB; 3) Reactor shell; 4) Reflector wall; 5) Control rods

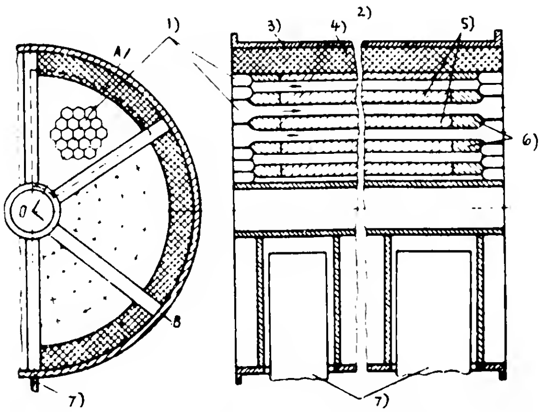

Fig.18 - Design of a Uranium-Beryllium Homogeneous Reactor for Direct Heating of Airflow

1) Tubes for airflow; 2) Section through AOB; 3) Reactor shell; 4) Outside reflector; 5) Active mass (uranium-beryllium alloy); 6) Rear face of reflector; 7) Control plates

To reduce the cross-sectional dimensions of the reactor, it is desirable to use metallic beryllium as the reflector material. Unfortunately, in this case it is impossible to use continuous-end reflectors. A certain amount of reduction in neutron leakage through the end surfaces is obtained by applying a layer of pure beryllium between the tubes at the front and rear surfaces of the reactor. In order not to crowd the access to and the exit from the reactor, the control devices are placed between the sections of the core and are displaced along the radius of the cylinder.

Let us review some data on a reactor designed on this basis. These data are obtained from approximate calculation based on familiar formulas derived from the theory of jet engines and the theory of nuclear reactors. The purpose of a reactor is to provide direct heating of air in an atomic turbojet aircraft engine, developing maximum static thrust at sea level of 32,000 kg. The maximum thermal capacity of the reactor is 300,000 kw, corresponding to a liberation of 258,000,000 kcal/hr. The maximum temperature of the heating surface of the core is 1100°C. The air is heated to a temperature of 950°C. The reactor core is cylindrical in form. The core is 1.9 m in diameter and in length, while the thickness of the side reflector, made of beryllium, is 15 cm. The thickness of the layer of pure beryllium of the front and rear surfaces of the reactor is 10 cm. The number of airflow tubes is 17,000. The inside diameter of each tube is 10 mm. The tubes are made of heat-resistant nickel alloy. The initial uranium^{235} charge is 70 kg. The combustion reserve, ensuring continuous operation at full capacity for 500 hrs, is 6.5 kg. The weight of the metallic beryllium, alloyed with uranium, is about 2000 kg. The combined weight of reactor and reflector is 9500 kg.

All three above designs assume the use of a homogeneous active mass. The use of heterogeneous nuclear reactors in aviation offers more limited possibilities, particularly for the direct heating of air. The core of a heterogeneous reactor, in this case, is complex in design and not very reliable in operation.

A shortcoming of nuclear reactors employing thermal neutrons is the necessity

of using only materials that are weak absorbers of thermal neutrons. Otherwise, the critical weight of the nuclear fuel increases considerably, and the most important advantage of thermal-neutron reactors may be canceled completely. In addition, reactors using thermal neutrons require cores of the largest critical size, relative to other types of reactors.

Fast-Neutron Reactors. These reactors use no moderators at all. This explains the major advantage of fast-neutron reactors, namely the fact that they have the smallest critical size of all types of reactors. However, this is not all.

We already know that the probability of useless capture of neutrons by the nuclei of various elements, during an increase in energy of the neutrons, decreases more rapidly than the probability of capture by nuclei of fuel available for fission. Therefore, the relative effect of poisoning in fast-neutron reactors is less than in thermal-neutron reactors. The lowered probability of absorption of neutrons of high energy permits a freer selection of materials for the working process in the reactor. Liquid metals may often be used as the intermediate heat-transfer agent, and the structural materials may consist of the best modern heat-resistant metals and alloys, regardless of their chemical composition.

In practice, the use of fast-neutron reactors in aviation is advantageous in cases in which there is a possibility of attaining high temperatures of the heating surface of the core, while liquid metal heat-transfer agents are used to dissipate the heat. Dissipation of heat in a stream of liquid metal is characterized by very high coefficients of heat loss, attaining 30,000 - 40,000 $\frac{\text{kcal}}{\text{m}^2/\text{hr} \cdot \text{deg}}$. Calculations show that even at a temperature of the heating surface of 1000°C, the critical dimensions of the core of a fast-neutron reactor are in good agreement with the dimensions required for heat dissipation if liquid metal is used as the heat-transfer agent.

Consequently, the use of fast-neutron reactors with liquid metal heat-transfer agents makes it possible to obtain greater power per unit volume of core than with

any other type of reactor or, what amounts to the same, with the smallest dimensions of core for each given power level. This is extremely important from the

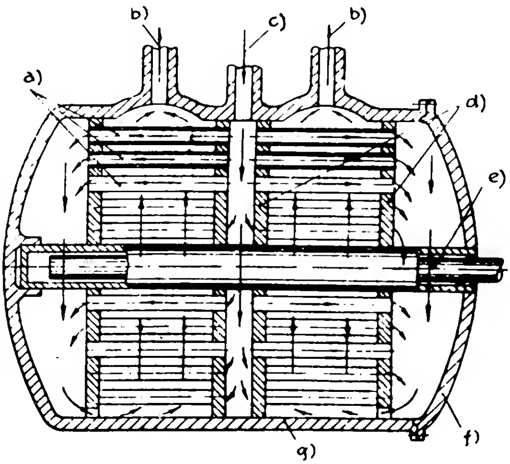

Fig.19 - Diagram of a Fast-Neutron Nuclear Reactor Using Molten Metal Cooling

a) Heat-producing elements; b) To heat exchanger; c) From pump; d) Retainer plates; e) Control rod; f) Cover of shell; g) Reactor shell

viewpoint of convenience of shielding the reactor and reducing the weight of the shields.

Figure 19 shows one of the possible designs of the core of a fast-neutron nuclear reactor using liquid-metal heat transfer. In the given case, there is no reflector. The core of the reactor is cylindrical in form and consists of two drums, each of which in turn consists of two retainer plates and an assembly of heat-producing elements. There is a gap of predetermined size between the two drums.

The resolution of the core into individual sections slightly increases the critical weight of the nuclear fuel but ensures a more reliable functioning of the reactor at high thermal loads. The shorter the length of the heat-producing elements at a given diameter, the less will they sag under their own weight, the less will be the deformation at nonuniform heating, and the less will be the vibration.

The shell of the heat-producing element is a tube with thin double walls. The nuclear fuel is housed in the hermetically-sealed space between the walls. The fuel elements are inserted in accurately machined apertures in the retainer plates, during assembly of the drums. Rigid mounting of these elements to the plates is provided only on one side, the outer plate aide. The heat-producing elements rest freely in the holes in the inner plates. This permits unrestricted expansion on heating.

The liquid-metal heat-transfer agent is forced into the gap between the drums by means of a pump, at a definite pressure. Here the current of heat-transfer agent divides in two. Moving through the tubes in an axial direction, the heat-transfer agent enters the front and rear chambers of the reactor. Both chambers are connected to the inner portion of the drums of each by means of channels in the lower portion of the outer plates. Through these channels, the heat-transfer agent enters the space between the plates from where it moves upward. Thus it washes the external surfaces of the heat-producing elements in a transverse direction.

In flowing over the inside and outside surfaces of the fuel elements, the heat-transfer agent is heated to a high temperature and enters the heat exchangers from the two upper chambers of the reactor. There it yields the heat obtained in the reactor to the air stream. From the heat exchangers, the cooled heat-transfer agent is recycled by pump to the reactor. The pressure in the reactor should be such as to prevent the heat-transfer agent from boiling within the core.

By means of equations familiar from the theory of heat exchange and the theory of nuclear reactors, it is not difficult to make approximate calculations for a

reactor designed on this basis. Below we derive certain data for such a calculation: The thermal capacity of the reactor is 300,000 kw. The fuel is uranium enriched by a 50% addition of the 235 isotope. The heat-transfer agent is fused lithium (melting point 180°C, boiling point at normal atmospheric pressure 1320°C). The maximum temperature of the heating surface is 1000°C. The lithium is heated from 750°C to 950°C. The diameter of the core is 0.8 m, and its length is the same. There are 8000 heat-producing elements. The outside diameter of each fuel element is 8 mm, and its inside diameter is 4 mm. The thickness of the shell is 0.5 mm. The thickness of the fuel layer is 1 mm. The material of the shell is heat-resistant nickel alloy. The weight of the structural materials in the core is about 900 kg. The initial charge of enriched uranium is 1100 kg. One half this quantity, i.e., about 550 kg, represents uranium^{235}. The combustion reserve is 6.5 kg. The total initial reserve of uranium^{235}, with allowance for reserves for poisoning and temperature effects, is about 9 kg. The initial reactivity excess is 0.012. The duration of continuous operation of the reactor at full capacity, determined by the reserve of fuel for combustion is 500 hrs. The dry weight of the nuclear reactor, without the reflector but including the control system, is 4000 kg. The weight of lithium in the reactor is 1500 kg. The average pressure of the heat-transfer agent in the reactor is about 20 atm.

The above example shows that the critical weight in the fast-neutron reactor is considerably greater than that of a thermal-neutron reactor. This is the major shortcoming of fast-neutron reactors and can be explained by the excessive neutron leakage. The necessity for high-enriched fuels and a large initial load places a certain limitation on the wide use of fast-neutron reactors in stationary power plants.

Nevertheless, the use of such reactors is very profitable since it creates the possibility of producing not only energy but highly effective nuclear fuel in a quantity greater than the amount actually burned.

If the core of a fast-neutron reactor is surrounded by a relatively thick layer of uranium^{238} or thorium, the loss of neutrons by leakage is no longer negligible. The absorption of these neutrons by a nuclei of uranium^{238} or of thorium^{232} results in the formation, respectively, of plutonium^{239} or uranium^{233}. In this case, as soon as the amount of newly formed highly efficient nuclear fuel is equal to the amount of "combusted" fuel, the reactor becomes a regenerative reactor, and as soon as this amount is exceeded, it becomes a breeder reactor. In aviation, such reactors cannot be used because of their exceedingly great weight.

Reactors Using Intermediate Neutrons. In such reactors, the quantity of the specially provided moderator is inadequate to moderate the neutrons down to thermal velocities. In their properties, such reactors are somewhere midway between thermal and fast-neutron reactors. By using a certain level of fuel dilution by a moderator, it is possible to make use of the advantages of both extreme types of reactors while eliminating their shortcomings to some degree. The dilution of nuclear fuel by a moderator results in an increase in the dimensions and weight of the nuclear reactor and slightly complicates the problem of protection from radiation; however, at the same time it reduces the needed initial charge of expensive nuclear fuel.

In addition, an increase in the dimensions of the core when dilution of fuel is used means primarily an increase in the area of heating surface. As a result, the same amount of heat may be transferred at a lower temperature. In the above-discussed reactor, using fast neutrons, a certain degree of dilution makes it possible to heat lithium to 950°C, at wall temperatures of the fuel elements differing from 1000°C (for example, 975°C). A reduction in the maximum temperature of the wall increases the reliability of operation of the heat-producing elements. Thus, if we dilute the fuel with a moderator, we may obtain an optimum combination of the engineering and economic possibilities for the development of an aircraft reactor. According to the foreign press, the majority of aircraft reactors now in the design stage are, as a matter of fact, in the class of intermediate-neutron reactors.

Calculations show that such a reactor is the most profitable for aviation if helium is used as the intermediate heat-transfer agent. The heat-transfer coefficient from the heating surface to the helium stream in high-temperature aircraft reactors is approximately $5000 \frac{\text{kcal}}{\text{m}^2/\text{hr} \cdot \text{deg}}$.

The design of the core of a reactor using intermediate neutrons depends upon the heat-transfer agent used and does not differ greatly from the above-described designs.

Major Difficulties in Developing Aircraft Nuclear Reactors

The development of nuclear reactors for use in high-speed atomic aircraft is hindered by the necessity to overcome a number of serious difficulties.

To begin with, to create high-power reactors despite small dimensions and weight, a large amount of very expensive material is required. The most costly material is the nuclear fuel. Above it was noted that the initial charge of high-efficiency fuel in a fast-neutron reactor amounts to several hundred kilograms. Today this figure is quite high, since the resources of high-efficiency fuels are still very limited. However, the production of nuclear fuel is being developed rapidly, processes of separating the isotope 235 from natural uranium are being perfected, and stockpiles of artificial, highly perfected fuels (uranium^{233} and plutonium) are being accumulated. Therefore it may be stated with confidence that in the not-too-distant future, the production of high-efficiency fuels will be adequate to permit the operation of a large number of aircraft reactors.

The progress in aircraft reactor design is also facilitated by large-scale development of regeneration or recovery (purification, rehabilitation) of nuclear fuel. We know that, of the total fuel charged into the reactor, only a small portion is expended. Thus, in the fast-neutron reactor examined above, of 550 kg of uranium^{235}, only 6.5 kg is "burned" during 500 hours of operation at top speed. The remaining fuel becomes unsuited for further use, due to contamination with fission

products. Regeneration, i.e., purification of the nuclear fuel from the contaminating impurities, makes most of it useful for re-use in reactors.

Serious difficulties are encountered in solving the problem of removing heat from the reactor. Moreover, the process of heat dissipation determines all major characteristics of an atomic power plant aircraft and the flying characteristics of an atomic airplane.

One of the difficulties consists in attaining high temperatures of the heating surface of the reactor core. The most widely used nuclear fuel, uranium, has proved a very capricious material. When metallic uranium is heated to over 660°C, the atoms in its crystal lattice undergo rearrangement, accompanied by a change in volume, density, and mechanical properties. In the temperature interval of 660 to 800°C, uranium is brittle, while above 800°C it is very soft and weak. Frequent heating and cooling causes progressive changes in the shape and dimensions of uranium blocks. A similar phenomenon results from the effects of irradiation and in particular of the intensive bombardment of the uranium nuclei by fission "fragments" and neutrons. The above properties of uranium cause serious difficulties in developing reliably operating fuel elements for high-temperature reactors.

To reduce the stresses in the materials constituting the shell of the heat-producing elements, set up as the fuel volume increases, the layer of fuel used must be as thin as possible. The effect of radiations on uranium may be weakened by alloying it, i.e., by fusing it with other metals, for example aluminum or beryllium. A uranium-beryllium alloy containing relatively little uranium is remarkably stable to radiation. The change in volume undergone by this alloy is negligible, even under very intensive bombardment by fission "fragments" and by neutrons.

The maximum temperature which can be attained in a reactor depends upon the choice of the material for the shells of the heat-producing elements. When heat-resistant steels are used, reaching a temperature above 700°C is practically impossible, since the main component of steel (iron) forms an alloy with metallic

uranium that fuses at a temperature of 725°C. The use of heat-resistant alloys based on nickel makes it possible to attain temperatures at the surface of the fuel elements of the order of 1000 - 1100°C. A shortcoming of nickel alloys is their high absorptivity for neutrons.

Good results can be obtained by the use of molybdenum (melting point, 2627°C). The probability of neutron absorption by molybdenum is second only to that of zirconium among the refractive metals. A shortcoming of molybdenum (violent oxidation on heating) is overcome by coating it with a spray-deposited silicon film. If an inert gas such as helium is used as the intermediate heat-transfer agent, no coating of the molybdenum shells is required. In this case, the temperature of the heating surface of the core may be raised to the order of 1500°C.

Even higher temperatures may be obtained if the fuel used is uranium oxide (UO_2) or uranium carbide (UC_2) and if the shells of the heat-producing elements consist of ceramic materials on the basis of aluminum, silicon, zirconium, etc.

The material of the shells of the heat-producing elements of an aircraft reactor has to work under exceedingly severe conditions. Temporary stresses are set up by the flow of heat-transfer agent and high-temperature stresses, due to uneven heating, are created in such materials. At high temperatures, oxidation and corrosion processes are activated and the destruction of structural materials by the flow of heat-transfer agent is accelerated. As a result of intensive irradiation by neutrons, the mechanical properties of the material are impaired, rendering the material more brittle. True, in an aircraft reactor, the effect due to irradiation is considerably weakened during heat-up of the material of the shells to high temperatures.

These causes have the effect that the period during which an atomic aircraft power plant can operate continuously becomes limited not so much by the possible reserve of nuclear fuel to compensate for the burned fuel, but by the length of re-

liable operation of the shells of the heat-producing elements of the reactor. We may hope that the best modern heat-resistant materials will result in a service life for aircraft reactors, not shorter than that presently attained by gas-turbine engines for aircraft.

Considerable difficulties are encountered in the selection of a heat-transfer agent. Gases, liquid metals, fused salts, high-pressure water, and other materials may be used for this purpose. The highest power per unit volume of core is obtained when liquid metal heat-transfer agents are used. In order for a nuclear reactor to function steadily and reliably, the stream of heat-transfer agent must consist of a single phase, without significant fluctuations in density, and the excess pressure in the reactor must be as low as possible. Therefore, the metals used as heat-transfer agents must have high boiling points. Conversely, in order to eliminate the possibility of consolidation in various portions of the circulatory system, the metals used must have a low fusing point. The heat-transfer agents must be chemically stable and have the lowest possible probability of neutron absorption.

Lead, bismuth, mercury, sodium, potassium, and lithium are among the metals that have these properties to a greater or lesser degree. Of the metals listed above, it would appear that lead and bismuth are the best. They have the highest boiling point (1740°C for lead and 1480°C for bismuth), have high chemical stability, and the lowest probability of neutron absorption. Alloys of lead and bismuth have in addition, an adequately low fusing point (somewhat less than 150°C). However, the use of lead, bismuth, and alloys of bismuth and lead, as well as of mercury as intermediate heat-transfer agents for atomic aircraft power plants has not yet proved possible. The low specific heat capacity and the high specific gravity of these metals has the final result of an extremely high total weight of the required quantities.

Approximate calculations show that, for flight of an aircraft weighing 150 tons at a height of 11 km at the speed of sound ($M = 1$), when the temperature of the

heating surface of the reactor is 1000°C, the weight of the liquid lead within the power plant has to be about 70 tons, i.e., almost one half the total flying weight. If we take into consideration that the weight of the shielding system is also about 70 tons, the impossibility of developing an atomic aircraft with this type of reactor becomes obvious. The use of lead and bismuth in atomic aircraft will become possible when science discovers more efficient methods of shielding from nuclear radiation, making possible a reduction in the weight of the shields to one fifth of the present level, with a simultaneous increase in the temperature of the reactor by at least 50%.

The use of mercury, moreover, leads to the necessity of providing high positive pressures in order to attain high temperatures, which leads to an even heavier power plant and a reduction in its reliability of operation. In addition, mercury is a highly avid neutron absorber. Calculations show that mercury can be used today only as the working medium in steam turbines designed to drive propellers for atomic turboprop engines or for air compressors of atomic ram-jet engines. However, it is only possible to produce a power plant of suitable weight if the vaporization of mercury takes place directly in the reactor. The problem of producing such a reactor, suitable for installation even on a subsonic aircraft, is exceedingly complex.

The use of sodium, potassium, lithium, and their alloys as intermediate heat-transfer agents makes it possible to reduce the weight of the metal in the system as compared to lead by a factor of more than 10, thus creating factual possibilities for the development of aircraft power plants operating on nuclear fuel. However, these metals are chemically highly active. They oxidize rapidly in air, and react violently with water. A general shortcoming of all liquid metal heat-transfer agents is the radioactivity that develops on irradiation with neutrons.

The weight of an atomic power plant may be lowered, and the difficulties due to the high chemical reactivity and radioactivity of the heat-transfer agents may

be reduced by using gaseous intermediate heat-transfer agents or by direct heating of the airflow in the reactor. Helium is the gaseous heat-transfer agent that offers the greatest possibilities. Helium is an inert gas of very low specific gravity, high specific thermal capacity, and almost nonexistent absorptivity for neutrons. The main difficulty in the practical use of helium is that of adequate sealing which will reliably prevent this substance from leaking from the system.

Direct heating of the air stream in a nuclear reactor makes it possible to eliminate this difficulty, but other and no less complex problems arise instead. We will discuss these below.

Obviously, the use of any heat-transfer agent involves certain specific difficulties. Which of the possible heat-transfer agents might be the preferable type? Today it is very difficult to answer this question. A correct answer might be possible only after a careful study of practical data in the development and operation of atomic aircraft power plants of various types with various heat-transfer agents and types of nuclear reactors.

Considerable difficulties are encountered in developing systems for the control of aircraft reactors. The problems of controlling stationary reactors have now been successfully resolved. The remaining problem is that of perfecting the existing systems, i.e., reducing their weight and dimensions and increasing their reliability and precision of operation.

The most serious difficulties are those in controlling fast-neutron aircraft reactors. Generally speaking, a fast-neutron reactor is more dangerous to use than a thermal-neutron reactor. If, for any reason, the reactivity reaches a value of 0.00755, the fission reaction will proceed at such a speed that the existing systems of emergency protection will no longer be able to prevent breakdown of the reactor.

However, a number of factors make an aircraft reactor, using fast neutrons, completely safe if the most elementary rules of operation are obeyed. The point

is that the initial reserve of reactivity in a fast-neutron aircraft reactor is very small. This is due to the relatively low possible operating period of an aircraft reactor and, consequently, the small reserve of fuel to replace the burned fuel. The reactivity reserve to compensate for poisoning and temperature effects is also small in a fast-neutron reactor. For example, to keep a 300,000 kw fast-neutron reactor operating for 500 hrs, the initial reactivity reserve need only be 0.012. In order for fission in this reactor to occur with prompt neutrons, more than half of the entire reactivity reserve must be engaged in the reaction, i.e., all control rods must be pulled out half-way.

The main difficulty in developing control systems for the operation of fast-neutron reactors lies in the problem of designing the control devices. To control such a reactor by means of fine absorption rods is not possible, as all known materials are weak absorbers of fast neutrons. One of the methods of control may be variation in the position of a certain portion of the nuclear fuel relative to the core. In this case, the control devices take the form of rods of nuclear fuel enclosed in protective metal cans and having an independent cooling system. A significant shortcoming here is the need to dissipate large amounts of heat from the control devices, leading to a considerable complication of design.

The low compensating capacity required by the control devices of a fast-neutron aircraft reactor permits a considerable simplification in their design. One of the possible designs for a control device is shown in Fig.20. The control device is in the form of a rod whose material is a good retarding agent, for example, graphite or beryllium. The rod is housed in a can consisting of a material that is a good absorber of slowed neutrons. When the rod is withdrawn, the fast neutrons pass through the thin walls of the can and participate in the fission reaction. If the rod is introduced into the core, a portion of the neutrons passing through it will be decelerated and will then be absorbed by the material of the can. The can may form a part of the channel wall rather than of the rod itself. The smallest

diameter per unit compensating capacity is provided by a beryllium rod. The material used for the rod may either be boron or boron carbide. In this case, the

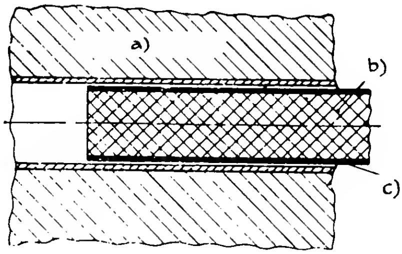

Fig.20 - Design of Control Rod for a Fast-Neutron Reactor
a) Core; b) Rod consisting of moderator; c) Can of material with good absorptivity for delayed neutrons

control rods of fast-neutron reactors differ from the rods of thermal-neutron reactors only in having a somewhat greater diameter. Cans are not necessary, since the boron, being a good moderator, is also a good absorber of delayed neutrons.

Above, we have examined only the major difficulties encountered in the development of aircraft nuclear reactors. Scientists, engineers, and designers working in the field of aircraft reactor construction, are often faced with the necessity of solving a number of other problems and of overcoming of other difficulties in the field of design, engineering, and operation. However, no matter how great these difficulties may appear at any moment, they are not insuperable.

Heat Exchangers

The heating of the working medium of an atomic engine directly in the reactor is often unprofitable and sometimes impossible.

In the reactor, it is possible to heat an intermediate heat-transfer agent

which yields its heat in a heat exchanger to the working medium of the engine. The presence of an intermediate heat-transfer agent of circulating pumps, and of heat exchangers results in an increase in the weight of the power plant. Therefore, an analysis of the system for the intermediate heat-transfer agent is of considerably greater importance for an aircraft atomic power plant than for any other type.

The intermediate heat-transfer agent system must primarily provide for dissipation of all the heat liberated in the reactor. Then this heat has to be transferred to the heat exchanger and there again transferred to the working medium of the engine. Let us examine, in sequence, how these problems are solved. In order to prevent fluctuations in the temperature of the reactor, exactly as much heat as is liberated must be dissipated. If more heat is liberated than is removed, the reactor temperature will rise. The automatic control will go into operation to reduce the liberation of heat in the reactor, and the desired reactor temperature will be restored. If, on the other hand, more heat is removed than liberated, this same temperature control will increase the liberation of heat to equalize it with the heat dissipation.

Thus, the reactor will produce exactly as much heat as the heat-transfer agent is able to remove from it.

The ability of the heat-transfer agent to accumulate heat is measured by its thermal capacity, i.e., by the amount of heat required to raise the temperature of 1 kg of heat-transfer agent by one degree. The amount of heat removed from the reactor per second is determined by the formula

$$Q' = cm\,(t_{fin} - t_{in}),$$

where Q is the amount of heat absorbed per second;

c is the thermal capacity of the heat-transfer agent;

m is the mass of the heat-transfer agent passing through the reactor per second;

t_{fin} is the final temperature of the heat-transfer agent;

t_{in} is the initial temperature of the heat-transfer agent.

The final temperature to which the heat-transfer agent is heated is limited by the mechanical strength or the corrosion properties of the reactor material. The initial temperature of the heat-transfer agent, i.e., the temperature at which it enters the reactor and the heat exchanger, is approximately equal to the temperature to which the working medium of the engine is heated. The greater the thermal capacity of the heat-transfer agent, the less of it will be needed to transfer the amount of heat which must pass through the reactor per second. When a heat-transfer agent of high thermal capacity is used, the total amount of heat-transfer agent in the system and its rate of flow can be reduced or, in other words, pumps of lower delivery can be used.

In order to transfer as much heat into the heat-transfer agent within the reactor as it is capable of absorbing, the reactor must have an adequate heating surface. The ability of the heating surface to transmit heat to the heat-transfer agent is measured by the coefficient of heat transfer. The coefficient of heat transfer indicates the quantity of heat that will be transmitted to the heat-transfer agent by 1 m^2 of heating surface in the course of an hour, when the temperature difference between the heating surface and the heat-transfer agent is one degree. The coefficient of heat transfer from a metal heating surface to air, under the service conditions in an aircraft reactor, amounts to several hundred $kcal/m^2 \cdot deg \cdot hr$, while to helium it is several thousand $kcal/m^2 \cdot deg \cdot hr$, and to liquid metal it is several tens of thousands of $kcal/m^2 \cdot deg \cdot hr$.

In order to provide for the transfer of heat to the heat-transfer agent, the area of heating surface of an aircraft reactor must be several hundred square meters. To have so large an area in a reactor of small dimensions, several thousand channels must be provided, through which the heated heat-transfer agent may branch out.

The transfer of heat from the heat-transfer agent to the working medium of the engine takes place in the heat exchanger. The heat-exchanging surface, at a heat-transfer agent and a working medium of specific parameters, is determined on the basis of the coefficient of heat transfer from the heat-transfer agent into the wall of the heat exchanger, of the coefficient of thermal conductivity of the heat-exchanger material, and of the coefficient of heat transfer from the walls of the heat exchanger to the working medium.

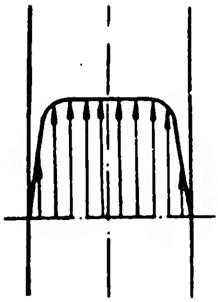

Fig.21 - Diagram of Velocity Distribution in Flow through a Tube of Round Cross Section

Both the heat-transfer agent in the reactor and the working medium in the heat exchanger are in motion and must overcome the force of friction with the heating substance. Figure 21 shows the velocity distribution of the flow of the body being heated, as it moves through a duct of round cross section.

A portion of the kinetic energy of the body being heated is expended in overcoming friction, which results in losses due to friction. The more intensive the heating of the moving substance, the greater will be the friction losses.

The heating of the substance driving an atomic engine, as we indicated above, is either effected directly in the reactor or in a heat exchanger. The design of the heat exchanger depends both on the heat-transfer agent used and on the working medium of the atomic power plant. But the general problem to be solved in all heat exchangers is that of providing a large heat-exchange surface in a heat exchanger of small dimensions and weight. The main types of heat exchangers of possible use in aircraft atomic power plants are the tubular (honeycomb) and the slotted types (Fig.22).

A tubular heat exchanger resembles the ordinary honeycomb radiator. It con-

sists of a large number of fine tubes in a single housing, with the tubes spaced at certain intervals. Through the tubes flows the working medium to be heated. The

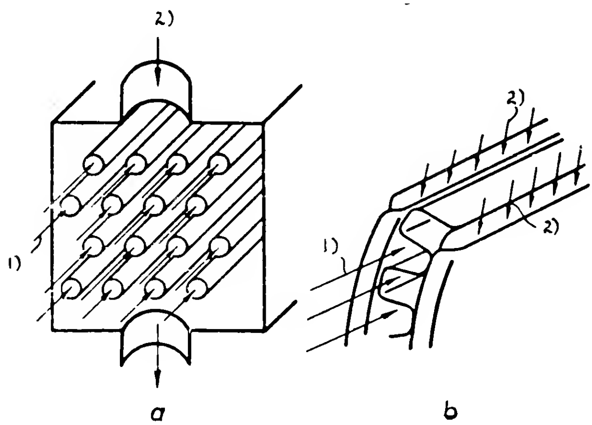

Fig.22 - Diagrams of Heat Exchangers: a) Tubular, b) Slotted

1) Air; 2) Helium

heat-transfer agent washes the outside of the tubes. The slot-type heat exchanger is a kind of "layer cake" whose successive layers are represented by the working medium of the engine and the heat-transfer agent. The layers are separated by thin sheets of metal, mechanically connected to provide rigidity of construction.

In both kinds of heat exchangers, the working medium of the engine and the heat-transfer agent may either be made to move in opposite directions or perpendicular to each other, or parallel in the same direction. It is obvious that the most effective form is that of opposing motion of the working medium and the heat-transfer agent, or what is known as countercurrent operation. In this design, the most uniform and highest heating of the working medium is obtained. In designing heat exchangers, an attempt is made to achieve the required heating of the working medium with the lowest possible friction losses.

A difficult problem is that of keeping the heat exchanger free of deformation due to temperature. On heating, as we know all metals expand, except for certain special alloys. The heating temperature of various portions of a heat-exchanger is not identical, so that the degree of heat deformation will vary. If no special measures are taken, the heat exchanger may break down. This danger is particularly great when the heat exchanger is heated and cooled along with the heat-transfer agent at the instant of starting and stopping the engine, when the inequality of heating is particularly great.

An important problem is that of developing reliably operating pumps for transferring the liquid-metal heat-transfer agents. The difficulties in providing reliable seals between the rotating shaft of the pump and its fixed housing, at exceedingly high temperatures, has led to the idea of substituting electromagnetic pumps for the usual mechanical pumps. The operating principle of electromagnetic pumps for liquid metals is based on utilization of the force of interaction of an electric current and a magnetic field. The tube with the liquid metal is placed within a magnetic field. Electrodes are inserted into the tube, and a current is sent through the metal. The liquid metal is thus subjected to an expulsive force and starts flowing through the tube.

The use of a liquid-metal heat-transfer agent requires an auxiliary system for heating the heat-transfer agent,since, at the usual temperatures of the ambient air particularly in winter, even the most fusible metal alloys available for use as heat-transfer agents will be in the solid state. This inconvenience is eliminated if gases are used as the heat-transfer agents. Hydrogen and helium, or a noncombustible mixture of hydrogen and helium, are particularly suited to this purpose. Less desirable are nitrogen, carbon dioxide, etc. In order to increase the coefficient of heat transfer and the volumetric thermal capacity of a gas, it has to be compressed to some tens of atmospheres.

An interesting special feature of the practical application of gaseous heat-

transfer agents is the possibility of providing for their "self-circulation". The gaseous heat-transfer agent compressor may be used to start the rotation of a gas turbine, by using the energy of the heat-transfer agent itself. In this case, the gaseous heat-transfer agent moves first from the reactor to the turbine, then to the heat exchanger, and from there to the compressor which compresses the gas and returns it to the reactor. The result is the usual closed cycle of operation of a gas turbine, one specific feature of which is the fact that it does not perform useful mechanical work. This explains the negligible reduction in the temperature of the gaseous heat-transfer agent within the turbine. This reduction in temperature is particularly small with hydrogen and helium.

The use of metals in vapor form as heat-transfer agents makes it possible to utilize not only the thermal capacity but also the latent heat of evaporation to transfer heat.

The desirability of this will be shown in the following example. Each kilogram of gaseous sodium condensed at a temperature of 880°C, liberates about 1000 kcal in a heat exchanger. The temperature of the heat exchanger wall, during this process is equal to the temperature of condensation. In order to transfer the same amount of heat to the heat exchanger by means of 1 kg liquid sodium at the same wall temperature, the sodium would have to enter the heat exchanger at an initial temperature of 4200°C. If we take as the initial temperature of liquid sodium the more realistic value of 1200°C, it would require 13 - 15 kg of liquid sodium to equal the efficacy of 1 kg of sodium vapor.

If we refrain from transferring heat by means of the thermal capacity of gaseous metals and make use only of the latent heat of evaporation, then the temperature in the entire heat-transfer agent system will be virtually identical. This temperature may be set at maximum permissible level for the structural materials of the heat-transfer system. When this is the case, the mechanical strength of the material will be utilized to a much greater degree, and materials not in such short supply can be used for the purpose. Thus, the use of vaporized metal heat-transfer agents is advantageous both in terms of weight and in terms of economics.

CHAPTER III

POSSIBLE DIAGRAMS OF AIRCRAFT ATOMIC POWER PLANTS (AAPP)

The structural design of an atomic power plant discussed in Chapter I (Fig.8) may be used both in aviation and in other fields of transport. To do so, it is necessary to replace the propeller by an electric generator and to use electric motors for rotating the propeller of a steamship, the driving wheels of an electric locomotive, etc.

It seems logical that atomic power plants of designs especially adapted for aviation will be developed to serve the modern types of aircraft engines. In accordance with the types of aircraft engines now in use, the possible types of AAPP may be divided into three major groups: 1) rocket engines; 2) three types of ram-jet engines: a) true athodyds, b) turbocompressor engines, c) motor-driven compressors; and 3)turboprop engines.

Each of these groups contains a large number of engine designs differing in complexity in accordance with the needs of various types of aircraft. Obviously, certain designs will be realized in the comparatively near future. Others will require a longer period of development from the scientific, technological, and particularly from the metallurgical viewpoint before they can become a reality.

Certain designs will probably remain on paper only.

In this Chapter, we will review the most typical designs of aircraft atomic power plants and will discuss the possibilities of their application.

Atomic Rocket Engines

Rocket is the name given to reaction engines that do not require atmospheric air for their functioning. The simplest type is the powder rocket engine. This type comprises a powder-filled cylindrical chamber, terminating in a specially profiled jet nozzle (Fig.23). As the powder undergoes combustion, a large quantity of

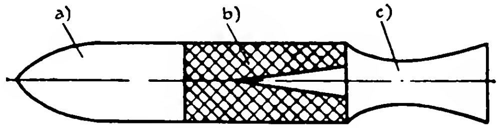

Fig.23 - Schematic Sketch of Powder Rocket

a) Warhead; b) Powder charge; c) Jet nozzle

gases is generated, which press outward in all directions. The pressure of the gases on the side walls is balanced (Fig.24). The force of the pressure of the gases on the front wall is incompletely compensated, since the area subject to gas

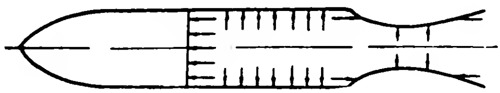

Fig.24 - Schematic Sketch of the Pressure Distribution of Combustion Gases

pressure on the nozzle side is smaller and since the pressure of the gases in a jet nozzle decreases with increasing velocity. This excess gas pressure is the reactive force. A reactive force is produced only if there is a difference in surface areas, i.e., if one side of the rocket is provided with an aperture through which the powder gases can escape. The development of reactive force is impossible without an ejection of gases. The greater the gas pressure, the greater will be the velocity

of flow and the reactive force.

A powder rocket engine, in which the powder undergoes combustion within a few seconds, is useful for aviation only as an auxiliary engine as a take-off assist for heavily loaded aircraft.

In liquid-fuel rocket engines, the period of operation is considerably longer. This type of engine has a cylindrical combustion chamber equipped with a jet nozzle (Fig.25). Fuel and oxidizer are sprayed into the combustion chamber. The fuel burns, while the oxidizer sustains the combustion. This results in the generation of high-temperature gases which are ejected through the jet nozzle, resulting in a

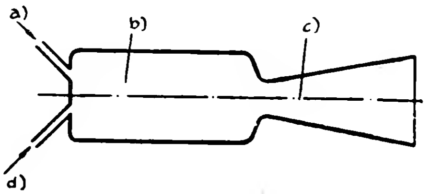

Fig.25 - Schematic Diagram of a Liquid-Fuel Rocket Engine

a) Fuel; b) Combustion chamber; c) Jet nozzle; d) Oxidizer

reactive force. The higher the temperature of the gases, the slower will be their discharge through the jet nozzle at the same pressure in the combustion chamber, i.e., at the same reactive force.

Obviously, the production of a reactive force in this type engine requires: 1) the production of a large quantity of gases compressed to high pressure; 2) the heating of these gases to the highest possible temperature; 3) the ejection of these gases through a jet nozzle at the highest possible velocity.

These same problems must necessarily be solved in an atomic rocket engine. The simplest design of such an engine is presented in Fig.26. A pump is used to deliver the working medium (i.e., the material for producing the gases) from the tanks to the reactor, under high pressure. Passing through the ducts of the reactor,

the working medium is converted to gas, heated to high temperature, and then ejected through the jet nozzle.

The period of operation of an atomic rocket engine is limited by the supply of working substance that can be housed aboard an aircraft. Because of the very high

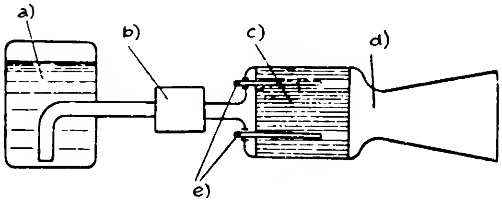

Fig.26 - Schematic Diagram of an Atomic Rocket Engine

a) Tank with working medium; b) Pump; c) Reactor; d) Jet nozzle; e) Control rods

consumption of this medium, an atomic rocket engine is unprofitable for flights at the altitudes at which modern aircraft and the aircraft of the future customarily fly. We will discuss the fields of application of this type of engine in Chapter V.

Ram-Jet Atomic Engines

In ram-jet atomic engines, the working medium is atmospheric air heated by the combustion of a liquid fuel, usually kerosene. The consumption of kerosene is no more than 2 - 3% of the air passing through the engine, a ram-jet engine is able to function for a considerably longer period of time aboard an aircraft than a liquid-fuel rocket engine. Ram-jet engines include: pulse jets, true athodyds, turbojets, and engines with motor-driven compressors.

The intermittent ram-jet engine (Fig.27) is a cylindrical tube, whose front end is closed off by a valve-type grill and whose rear section ends in a jet nozzle. This engine functions in the following manner: The fuel (gasoline) is injected through nozzles and is immediately ignited by a sparkplug. The gasoline combustion

products and the hot air seek to escape through the jet nozzle. The pressure of the gases on the valve-type grill closes the valves and thus produces thrust. As the gases are ejected from the jet nozzle at high velocity, they continue to flow by inertia even after the pressure in the combustion chamber has returned to atmospheric

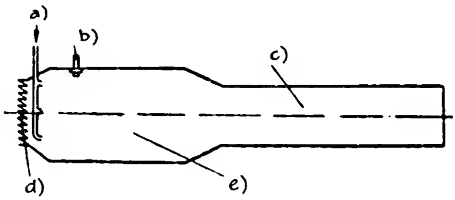

Fig.27 - Design of Intermittent Ram-Jet Engine

a) Fuel; b) Sparkplug; c) Jet nozzle; d) Valve grill;

e) Combustion chamber

pressure. This creates a vacuum in the combustion chamber and a new charge of atmospheric air is sucked through the valves. Then gasoline is again injected, and the cycle is repeated. A total of 80 - 100 cycles occur in this engine within one

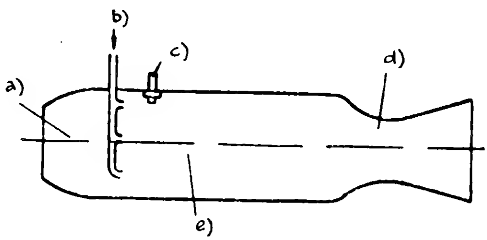

Fig.28 - Schematic Sketch of a Ram-Jet Engine

a) Diffuser; b) Fuel; c) Sparkplug; d) Jet nozzle;

e) Combustion Chamber

second, each accompanied by pressure surges or pulsations. Therefore this type of engine has become known as a pulse jet.

The ram-jet engine is simpler in construction (Fig.28) and requires no valve grill. However, in order for a ram-jet engine to function, the aircraft on which it is installed must fly at high speed. The relative air sucked into the nose of the ram jet, called the diffuser, is decelerated. Its velocity decreases, while the pressure increases. Fuel, ignited by a sparkplug, is injected into the air compressed by the velocity head. The combustion products mixed with air are ejected through the jet nozzle at high velocity. The reactive force results from the pressure drop between the nose (at the diffuser) and the rear (at the jet nozzle).

In 1929, B.S.Stechkin, member of the Academy, was the first in the world to develop and publish the fundamentals of the theory of ram-jet engines. In addition to a number of other important laws, he determined the relationship between the reactive force of a ram-jet engine and the velocity difference between the exhaust of gases from the jet nozzle of the engine and the flying speed:

$$P = G_a \frac{c_f - c_{f\ell}}{g},$$

where P is the reactive thrust;

G_a is the airflow through the engine;

c_f is the rate of flow;

$c_{f\ell}$ is the flying speed;

g is the acceleration of gravity.

The equation permits determination of the reactive force, without knowledge of the gas pressure distribution within the engine, merely on the basis of the flying speed, the exhaust velocity of the gas, and the flow of air through the engine.

The greater the exhaust velocity, the greater will be the reactive thrust.

A major shortcoming of the ram-jet engine is the fact that it can create a reactive force only at high flying speeds. The turbojet engine (Fig.29) lacks this shortcoming. The operating principle of this engine is as follows: As the engine is run on the ground, air is sucked in by the compressor and compressed to several at-

mospheres pressure. The compressed air is then directed into the combustion chamber. The fuel is injected into this chamber. The combustion products rotate a turbine whose shaft is connected with the compressor; the combustion products are then

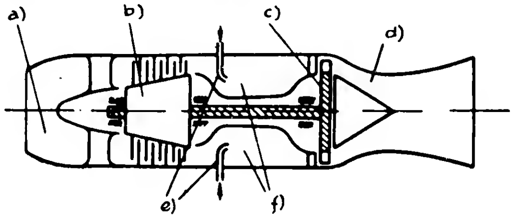

Fig.29 - Diagram of a Turbojet Engine

a) Diffuser; b) Compressor; c) Turbine; d) Jet nozzle;

e) Kerosene injectors; f) Combustion chamber

ejected through the jet nozzle. In this engine also, the reactive force is the resultant of the forces of the air pressure and the combustion products over the entire inside surface of the engine, and also may be calculated by Stechkin's equation.

At the dawn of the development of ram-jet engines, when they were still of low power, not a turbine but an internal combustion aircraft engine was used for driving the compressor. This type of ram-jet engine was called an engine with motor-compressor drive. This type did not come into wide use, in view of the fact that a gas turbine can develop a much greater power than an internal combustion engine of the same weight.

Except for the pulse jet, all types of ram-jet engines may be run by atomic energy. Let us examine in sequence a number of probable designs of atomic ram-jet engines.

Atomic Ram-Jet Engine (ARJE)

The atomic ram-jet engine (Fig.30) is the simplest type of atomic power plant.

What it amounts to is a "flying reactor" with a diffuser in the nose and a jet nozzle at the rear.

Within the speed range exceeding the speed of sound by a factor of not more than 3 - 4, the ram jet develops increased thrust in proportion to the flying speed. Therefore, this type is used for high-speed aircraft. In flight at supersonic speeds, a shock wave develops ahead of the engine, which results in retardation of the increase in engine thrust as the flying speed increases. Installation ahead of the engine of a cone such as that shown in Fig.30 facilitates reduction in the intensity of the shock wave and thus leads to a reduction in the loss of thrust. The cone can be used for housing electric motors to operate the control rods of the reactor.

One of the major parameters used for rating of jet engines is the specific thrust. If the thrust of an engine is divided by the number of kilograms of air passing through the engine per second, the magnitude of the specific thrust is obtained. The greater the thrust created by each kilogram of air, the more ideal is the engine.

The specific thrust of a ram jet is determined by the altitude and speed of flight, the design of the diffuser and jet nozzle, and the temperature to which the air is heated in the engine. The higher the temperature of the air, the greater the specific thrust. In modern ram-jet engines, the air is heated to approximately 1500°C. It is impossible today to heat the air in an ARJE to this temperature. The structural materials of modern reactors can only withstand temperatures of the order of 1000 - 1100°C, and the temperature of the heated air will be even lower than this. Moreover, the friction losses, as air moves through the channels honeycombing the reactor, will be considerably greater than the losses in the combustion chamber of the ordinary ram-jet engine. The result is that the specific thrust of and ARJE is inferior to that of a conventional type of ram-jet engine.

However, the thrust of an engine is determined not only by its specific thrust

but also by the air throughput, i.e., by the quantity of air passing through the engine per second. If the dimensions of an ARJE are larger than those of a conventional ram jet, then a larger amount of air will flow through it, and its thrust

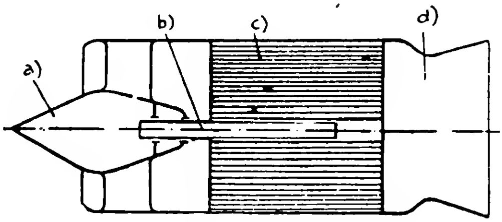

Fig.30 - Schematic Diagram of an Atomic Ram-Jet Engine

a) Nose cone; b) Control rod; c) Reactor; d) Jet nozzle

will be greater. There is no need to worry about the fact that the increase in size of the ARJE will increase the consumption of nuclear fuel. A fuel supply sufficient for the entire possible service life of an ARJE is charged into the reactor at a single time so that there is no need to refuel during the life of the engine.

The maximum flying speed may be increased either by raising the thrust of the engines or by reducing the drag of the aircraft. If the drag is reduced and the thrust remains the same, the maximum speed will increase.

In terms of increasing the maximum speed of the aircraft, the perfection of an aircraft engine is rated by its frontal thrust. The frontal thrust of an engine is the thrust of that engine per square meter of frontal cross-sectional area. The cross-sectional area determines the drag experienced by the engine. The greater the frontal thrust, the smaller the cross-sectional area of the engine has to be to reach a given total thrust, or the greater will be the maximum flying speed attainable. Therefore, it is desirable to have the greatest possible frontal thrust.

At a given rate of airflow, the cross-sectional area of the engine is determined either by the dimensions of the diffuser or by the dimensions of the reactor

or of the jet nozzle. The diameter of the jet nozzle usually is less than that calculated in the original design, so as to prevent the jet nozzle from exceeding the overall dimensions of the engine. This "cutdown" of the jet nozzle causes some reduction in thrust, but at the same time the drag of the engine is decreased to an even greater degree. Therefore, it may be considered that the cross-sectional dimensions of an ARJE are determined either by the diffuser or by the reactor. Calculations show that only at very high flying speeds, approximately three times as high as the speed of sound, will the lateral dimensions be determined by the diffuser. At speeds less than 2.5 times the speed of sound, the diameter of the reactor,will exceed the diameter of the diffuser. This means that, in order to increase the frontal thrust, an effort must be made to reduce the cross-sectional area of the reactor.

If the air throughput of the engine is taken as given, then at a flying constant speed the cross-sectional area of all channels of the reactor will be smaller, the greater the rate of airflow through these ducts.

Heating of the air as it flows through the ducts is accompanied by an increase in its velocity, since the density of air decreases with increasing temperature while the cross-sectional area of the duct remains constant. The air velocity at the reactor outlet is several times greater than at its inlet. At a given air velocity at the inlet, its speed at the outlet of the reactor will equal the speed of sound. A further increase in the air velocity at the reactor inlet and, consequently, free passage of air through the engine is impossible. What happens is "cutoff" of the reactor.

An engine will have its greatest frontal thrust when the velocity of the air at the reactor outlet is equal to the speed of sound. If, in this case, the temperature of the heating surface is increased, the temperature of the air will also rise. This causes the velocity of the air at the reactor outlet to increase somewhat, but as usual it will equal the speed of sound when a temperature of specific magnitude

is attained. The velocity of the air at the reactor input decreases and the passage of air through the engine is reduced.

What will be accomplished with such an engine? The specific thrust will increase with increasing air temperature increases, and the rate of flow will decline. The thrust of the engine, equal to the product of the specific thrust and the airflow, will either not change at all or change very little. Calculation results showing the relationship between frontal thrust and speed of sound for two ARJE, in which the temperatures of the heating surface of the reactor are 1100°C and 1600°C, respectively, are presented in Fig.31 in the form of curves. A comparison of these curves shows that it is not always necessary to strive for an extraordinary increase in the air temperature by increasing the temperature of the heating surface of the reactor.

How can the thrust of an ARJE be varied in flight? The thrust of a conventional ram jet is changed by changing the amount of fuel injected into the air. Control of the thrust of an ARJE is even simpler and may be accomplished by means of the regulating (control) rods of the reactor. To reduce the thrust of an ARJE, the rod is pushed into the reactor, thus reducing the amount of heat liberated by the reactor to the desired level. This causes the air temperature at the reactor output to drop and, consequently, reduces the thrust. To increase the thrust, the thermal capacity of the reactor must be increased by withdrawing the control rods. To prevent an excessive rise in temperature of an ARJE reactor, a temperature control has to be provided.

In addition to the above-discussed ARJE design, in which the air is heated directly in the reactor, another design may be conceived, namely one involving heating of the air by means of an intermediate heat-transfer agent. Figure 32 presents a schematic diagram of an ARJE in this category. The air compressed by the velocity head is heated in a heat exchanger. The transfer of heat from the reactor to the air is performed by an intermediate heat-transfer agent, which is circulated by a

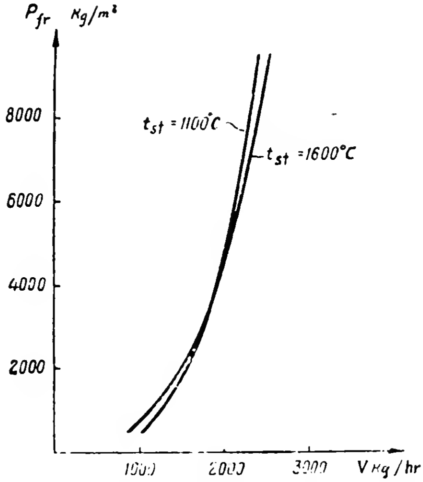

Fig.31 - Ratio of Frontal Thrust of an Atomic Ram-Jet Engine to Flying Speed

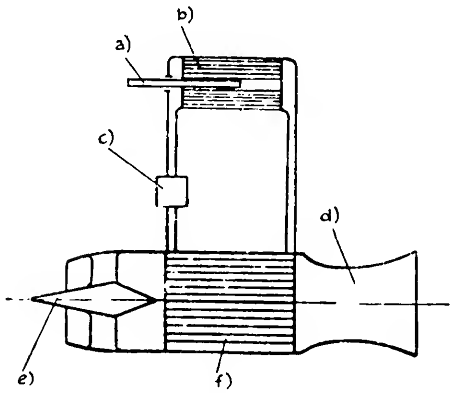

Fig.32 - Schematic Sketch of an Atomic Ram-Jet Engine with Intermediate Heat-Transfer Agent

a) Control rod; b) Reactor; c) Pump; d) Jet nozzle; e) Nose cone; f) Heat exchanger

special pump. This ARJE design permits the use of a much smaller reactor. The coefficient of heat transfer from the heating surface of the reactor to the heat-transfer agent is many times larger than to air. Therefore, the heating surface of the heat-transfer agent need be only a fraction of that in the former case, and the dimensions of the reactor may be reduced accordingly.

However, atomic ram-jet engines using intermediate heat-transfer agents are more complex, both in design and in operation. For example, they will have poor pickup. Pickup is the capacity of an engine rapidly to gain thrust at the desire of the pilot, from any operating condition up to maximum thrust. The greater the pickup of the engine, the more maneuverable the aircraft will be. The thrust of an ARJE with direct heating of air in the reactor begins to increase at the instant of pulling out the control rod, whereas the thrust of an ARJE with an intermediate heat-transfer agent begins to increase only after the heat-transfer agent is heated slightly.

A basic drawback of the ram-jet engine is its inability to produce thrust when on the ground and at low flying speeds. This shortcoming makes it impossible to use an ARJE as the sole form of propulsion. It must necessarily be used in combination with other types of engines to permit the aircraft to take off and to accelerate to the speed at which the ARJE produces adequate thrust.

Atomic Turbojet Engines (ATJE)

The turbojet engine is the predominant type used in modern jet aircraft. This is due to the fact that the engine is simpler in design than the turboprop engine, which can compete with it insofar as fuel consumption is concerned. In addition, an aircraft with a turbojet engine can reach significantly greater speeds than one with a turboprop engine, in view of the fact that, at supersonic flying speeds, the efficiency of thrust production by a propeller diminishes.

The ATJE is the simplest of atomic aircraft engines which can be used entirely

alone. Installation of an ATJE on an aircraft permits it to take off independently, to fly with good maneuverability over the entire possible range of speeds and altitudes, and also to make a normal landing. Let us discuss the possible design variants of an ATJE. The simplest is a design that differs from that of the ordinary turbojet engine only in that the combustion chamber is replaced by a reactor. This design is illustrated in Fig.33. Air from the compressor enters the reactor, which is placed between the compressor and the turbine. A portion of the energy of the heated air is consumed in the turbine for rotating the compressor. Another portion is converted into the kinetic energy of the exhaust from the engine, within the jet nozzle.

Proper selection of the compression ratio of the compressor is a major factor

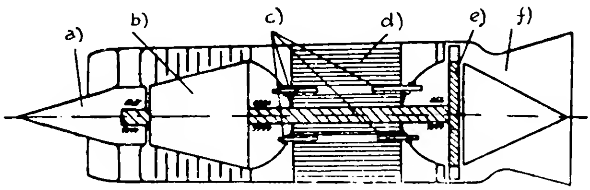

Fig.33 - Schematic Sketch of an Atomic Turbojet Engine
a) Nose cone; b) Compressor; c) Control rods; d) Reactor;
e) Turbine; f) Jet nozzle

in designing a turbojet engine with high specific parameters. In projecting an aircraft engine, the designer knows the speed at which the aircraft and its engine will fly. He selects a compression ratio permitting development of the greatest possible thrust at this calculated flying speed, with the lowest possible fuel consumption and the smallest possible engine weight. It is usually impossible to satisfy all three of these requirements at once. If the compression ratio is so selected that the specific thrust of the engine is at its maximum, the fuel consumption will be high. If minimum possible fuel consumption is desired, the specific thrust will

decrease. The designer determines which factor is more important for the aircraft and determines the compression ratio on that basis. Thus, an engine designed for a long-range bomber must have minimum fuel consumption. As a result, the saving in fuel weight during a flight of many hours duration permits an increase in range. On the other hand, interceptor aircraft require maximum frontal thrust. The excess consumption of fuel that is inevitable in this case is not of importance, since the flying time of such an interceptor may be measured in minutes.

How then shall we approach the selection of the compression ratio for an ATJE? The fact that ATJE are used for high-speed aircraft indicates that the compression ratio must be such as to yield maximum frontal thrust. It is desirable, of course, that the engine weigh as little as possible. However, it must not be forgotten that the main portion of the weight of an atomic aircraft engine is the weight of the radiation shielding. Therefore, a reduction in engine weight at the expense of a reduction in frontal thrust will hardly be desirable.

Thus we have come to the conclusion that the compression ratio of the compressor of an atomic engine for aircraft must be such as to give maximum frontal thrust. As in conventional turbojet engines, it is to be expected that, with an increase in the calculated flying speed, the compression within the compressor will be reduced. This is explained by the increase in compression due to the velocity head. For example, for sea-level operation of an engine the optimum compression ratio of a compressor is six. At flying speeds equal to that of sound, the compression of the air due to the velocity head is a little less than two, and in order to attain a total compression ratio of six, the compression in the compressor need be only slightly above three. This is a crude example and does not reflect all the complexities of the phenomena that must be taken into consideration in calculating the optimum degree of compression within a turbojet compressor designed to yield high flying speeds, but it is clear from this that, at increasing flying speed, compression ratio of a turbojet compressor should be reduced.

When the daily press carried the first reports on possible designs of atomic aircraft engines, it was believed that the compression ratio of an ATJE engine would have to be considerably greater than that of a conventional turbojet engine. This was explained by the increase in heat emission from a reactor with increasing pressure of the airflow through this reactor and the attendent possibility of reducing the size of the reactor accordingly. The possibility of designing atomic ram-jet engines was completely denied. It was held that the degree of compression of the air due to the velocity head, even at high flying speeds, would be insufficient to drive the air through the ducts of the reactor. Later, when the required calcula-

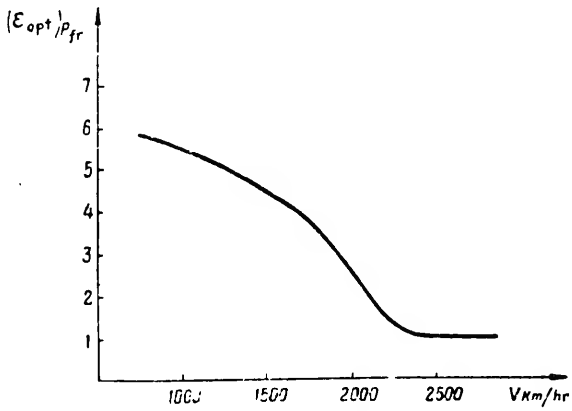

Fig.34 - Optimum Calculated Compression Ratio of an Atomic Turbojet Engine, to Obtain Maximum Frontal Thrust, as a Function of the Flying Speed

tions had been made, it appeared that the optimum compression ratio of an ATJE compressor, calculated to yield a maximum frontal thrust, differs much less from the optimum compression ratio of a conventional turbojet than had previously been assumed. The nature of the relationship of the optimum compression ratio of the compressor of an ATJE and the flying speed is illustrated in Fig.34. This curve per-

mits selecting the compression ratio of the ATJE compressor for any desired flying speed. It is obvious that, at high flying speeds of M = 2.5 - 3 or more, the optimum compression ratio is unity, i.e., that at these speeds an atomic ram-jet engine develops greater frontal thrust than does an atomic turbojet engine. This again confirms the desirability of using ARJE for high flying speeds.

As indicated above, an increase in the compression ratio of the compressor for an ATJE results in a better dissipation of heat from the reactor and permits a reduction in its weight. However, at high flying speeds, the total degree of compression of the air due to the velocity head and due to the compressor rises excessively. The temperature of the air past the compressor increases to such a degree that all that is possible within the reactor is a very small rise in the heating of the air

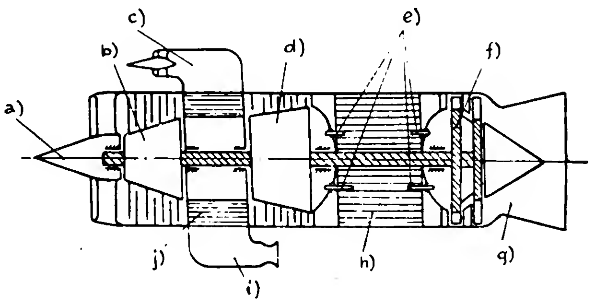

Fig.35 - Atomic Turbojet Engine with Two-Stage Compressor and Intermediate Cooling of Air'

a) Nose cone; b) First-stage compressor; c) Cooling-air scoop; d) Second-stage compressor; e) Control rods; f) Two-stage turbine; g) Jet nozzle; h) Reactor; i) Outlet for cooling air; j) Heat exchanger

to that permissible in terms of the thermal strength of the reactor. The thrust of an engine decreases with a reduction in the amount of heat delivered to the air. A loss of thrust may be avoided if the air is cooled during the compression process.

With this object, the ATJE compressor may be designed as a multistage type, with cooling after each stage. Figure 35 illustrates a two-stage ATJE compressor. The heat exchanger between the compressor stages functions basically as a ram-jet engine when both air intake and ejection are properly laid out, and will create additional thrust.

The simplest design for an ATJE, illustrated in Fig.33, permits obtaining the highest specific parameters. In this case, the air duct becomes a uniflow duct where the airflow through the engine is at all times parallel to the engine axis

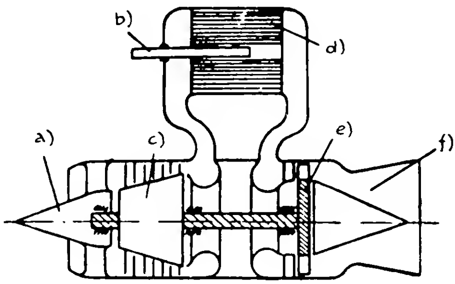

Fig.36 - Diagram of an Atomic Turbojet Engine with Reactor Outside the Engine
a) Nose cone; b) Control rod; c) Compressor; d) Reactor; e) Turbine;
f) Jet nozzle

in a straight line, so that the hydraulic resistance is at a minimum. The air is heated directly in the reactor without an intermediate heat-transfer agent. This simplifies the design and eliminates excessive heat loss. However, this design, which is simple in principle is exceedingly difficult to realize. The shaft connecting the turbine with the compressor has to pass through the reactor. Cooling the shaft under these conditions becomes a difficult and actually, one might say, the key problem. The point is that the shaft not only becomes heated as a result of heat transfer from the hot reactor parts, but considerable liberation of heat occurs

within the shaft itself, due to the scattering and absorption of neutrons and gamma rays by the shaft material. So much heat is liberated in the shaft that cooling of the shaft changes from a simple engineering matter to a complex problem, whose solution will govern the very possibility of developing an ATJE on the basis of this "simplest" design.

In order to avoid the effect of reactor radiations on the shaft, the reactor could be installed outside the engine and deliver the air to the engine through special ducts. Figure 36 illustrates an engine of this type. The air duct of such an engine can no longer be considered a ram jet. The air passing through the engine and the reactor undergoes several changes in direction. This results in additional

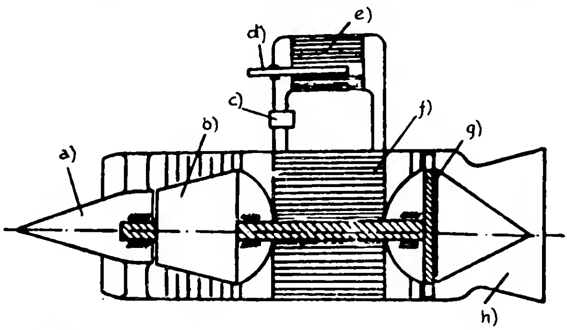

Fig.37 - Schematic Sketch of an Atomic Turbojet Engine with Intermediate Heat-Transfer Agent

a) Nose cone; b) Compressor; c) Pump; d) Control rod; e) Reactor; f) Heat exchanger; g) Turbine; h) Jet nozzle

hydraulic losses, which reduce the specific thrust of the engine. In addition, there are inevitable heat losses through the walls of the ducts as the air moves from the reactor to the turbine, which also impairs the specific parameters of the engine. However, the reactor in this case has been moved far outside the engine, and provision for shielding from radiation therefore becomes significantly simpler.

To realize an ATJE on the basis of this general scheme apparently is easier than on the basis of the design presented in Fig.33. An increase in hydraulic losses can be prevented by using a slightly more complicated design. Figure 37 shows a design for an ATJE using an intermediate heat-transfer agent. The function of the intermediate heat-transfer agent is that of transmitting heat from the reactor to the air. The advantages of this ATJE are the same as those of an atomic ram-jet engine with intermediate heat-transfer agent: a comparatively small reactor, and lower hydraulic losses than those in the engine designed in accordance with Fig.36. The shortcomings lie in the field of greater complexity of design and operation.

Many modern turbojet engines are equipped with boosters. Boosting is an increase in the thrust of an engine above its maximum for a short period by means of some "overloading" of the engine. The majority of turbojet engines with boosters are provided with what is known as afterburner chambers placed between the turbine and the jet nozzle. Considerably more air is delivered to the combustion chamber of a turbojet engine than is required for burning the injected fuel; consequently, the combustion products still contain a considerable amount of oxygen. Additional fuel is injected into the after burner in which this residual oxygen is used for combustion. The temperature of the gases rises, the exhaust velocity increases, and the thrust is augmented. However, the fuel consumption almost doubled in this procedure. The temperature of the engine parts starts to rise sharply. Therefore, boosting is possible only for a brief period of time, not more than a few minutes. Usually, the boosters are turned on when there is need for rapid acceleration or for gaining altitude.

In this connection, the thought arises as to whether it might be possible to reheat the air after it has passed through the turbine of an ATJE? The simplest solution is supplementary heating with an intermediate heat-transfer agent. Figure 38 shows a schematic sketch of an ATJE with supplementary heating of the air downstream of the turbine. The heat-transfer agent moves from the reactor first to

the auxiliary heat source and then, having surrendered part of its heat, proceeds to the other section of the heat exchanger where the heat going to the turbine is heated. The temperature of the air upstream of the turbine will be somewhat lower than is the case without supplementary heating; in addition, the dimensions of the turbine have to be increased somewhat so as to keep the power of the turbine at the same level. It is possible that, as far as weight is concerned, it may prove more advantageous to use two independent circulation circuits for the heat-transfer agent: one for heating the air upstream of the turbine and the other for supplementary heating of the air downstream of the turbine.

An objection to the use of an ATJE in which the air is heated directly in the

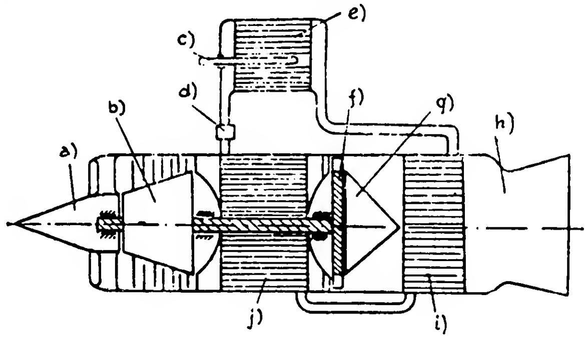

Fig.38 - Schematic Sketch of an Atomic Turbojet Engine, with the Air Heated Downstream of the Turbine

a) Nose cone; b) Compressor; c) Control rod; d) Pump; e) Reactor; f) Turbine; g) Cone; h) Jet nozzle; i) Auxiliary heat exchanger; j) Heat exchanger

reactor may be raised on the grounds that the air, having passed through the reactor, will become radioactive and will constitute a hazard for the ground crew. Let us define the extent of this possible danger. The bulk of the radioactive radiation

in the air will be argon, which constitutes 0.94% of air. Radioactive radiations may be produced by one of the isotopes of oxygen, by water vapor in the air, and also by dust. The air passing through the engine is constantly intermixed with the ambient atmospheric air, so that the concentration of radioactive argon drops rapidly. In practice, at the point where the temperature in the stream of hot air emitted from the engine drops to the point where a person entering this air stream does not suffer a burn, the radioactivity of the air has also dropped to below the danger point for the human organism. Somewhat more dangerous is the radioactive dust that may have passed through the reactor. This dust, settling on the airfield, may create a significant radiation level of rather long duration. The best methods of counteracting this phenomenon are those used to prevent dust from forming on an airfield: laying of concrete runways, proper dust removal from these strips, wetting with water before aircraft take-offs, etc.

In closing this Section, let us review data for calculation of the ATJE shown in Fig.33. The weight of the engine, including the reactor and reflector surrounding the reactor, will be 15 tons. The length of the engine will be 6.5 m and its diameter 2.3 m. At sea-level operation, the engine will develop a thrust of 32 tons. An aircraft with a flying weight of 130 tons, equipped with two such engines, will be able to develop a maximum flying speed of 2100 km/hr at an altitude of 11,000 m. The aircraft will be able to fly at this speed and altitude more than 1,000,000 km (26 times around the earth) without the need for refueling. A total of 15 kg of uranium^{235} will be consumed in the course of such a flight.

<u>Atomic Turbojet Engine with Motor-Driven Compressor (ATJEMC)</u>

It had been indicated above that supplementary heating of the air past the turbine causes an increase in engine thrust. It is obvious that the same result will be obtained if an auxiliary engine, not utilizing the energy of the air heated in the heat exchanger or the reactor, is used for driving the compressor. A steam or

gas turbine may be used for this purpose. Figure 39 shows a schematic sketch of an ATJEMC with a mercury-vapor turbine. The mercury turbine operates on a closed cycle. A pump forces the mercury under high pressure through the reactor. The mercury is heated there and converted into vapor. The mercury vapor enters the turbine, rotates it and, after passing through a condenser, condenses. The liquid mercury is recycled by the pump into the reactor.

The mercury turbine rotates the compressor, which takes in air, compresses it,

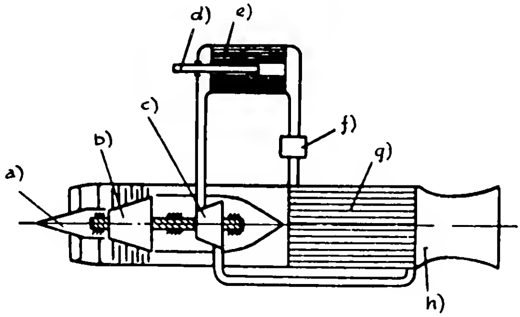

Fig.39 - Schematic Sketch of an Atomic Turbojet Engine, Using a Steam Turbine for Driving the Compressor

a) Nose cone; b) Compressor; c) Mercury turbine; d) Control rod; e) Reactor; f) Mercury pump; g) Condenser; h) Jet nozzle

and drives it to the condenser. In the condenser, the air absorbs the heat of the mercury, becomes heated, and is ejected through the jet nozzle at high velocity. The increase in the velocity of the air passing through the engine is accompanied by the production of reactive thrust, which, as in all ram-jet engines, represents the difference between the pressure of the air at the frontal area of the engine and the air pressure directed to the rear.

A reactor operating on this principle must use fast neutrons, since mercury is an avid absorber of thermal neutrons. However, it will be rather difficult to de-

sign a fast-neutron reactor. The point is that the mercury, passing through the reactor, is converted from liquid to vapor. Its density will differ at various points along its path through the reactor, the absorption of neutrons will be different, and the conditions of heat transfer will vary. All these difficulties indicate that it will be more desirable to heat the mercury in a heat exchanger by means of an intermediate heat-transfer agent.

Another possibility also exists. A gas turbine, e.g., a helium turbine, instead of the mercury turbine can be used. Figure 40 presents the design of an

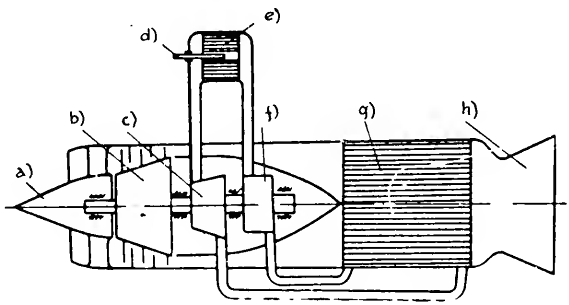

Fig.40 - Diagram of Atomic Turbojet Engine with Gas Turbine Driving Compressor

a) Nose cone; b) Air compressor; c) Gas turbine; d) Control rod; e) Reactor; f) Gas compressor; g) Heat exchanger; h) Jet nozzle

ATJEMC of this type. To supply the same power to an air compressor, the power of a helium turbine must be several times higher than the power of a mercury turbine. This is due to the fact that a colossal power, several tens of times greater than that required for a mercury pump, is needed to drive a helium compresoor. For example, if the power of the helium turbine is 150,000 hp, more than 100,000 hp are consumed in rotating the helium compressor, and less than 50,000 hp remain for the air compressor. To provide the same power for an air compressor, a mercury turbine

would need 53,000 - 54,000 hp, i.e., slightly more than a third of the amount required by a helium turbine. However, the power required by the reactor in both cases is approximately the same, since the efficiency of the helium turbine under the conditions existing in an ATJEMC is considerably higher than with a mercury-vapor turbine.

Both the pressure of the helium and the pressure of mercury vapor at the input to the turbine must be several tens of atmospheres. A similar or even somewhat higher pressure is needed in the reactor. This clearly indicates the need for providing a strong and reliable reactor. The thickness of the walls of the steel pressure vessel of the reactor must be several centimeters, and dependable cooling of the pressure vessel must be provided.

In the ATJEMC whose designs are illustrated in Figs.39 and 40, the air is heated by the working medium of the turbine, which is mercury vapor condensing into liquid mercury, or helium. The working medium is delivered from the turbine to a condenser. Only when this happens, as we know from the Second Law of Thermodynamics, will the turbine be able to do work. The condensation of mercury vapor and the cooling of helium in the condenser take place as a result of heat exchange with the air. The air is heated under these conditions. In order to obtain high thrust, the air must be heated to the highest possible temperature. In the best case, the air temperature will be 50 - 100° lower than the temperature of the working medium arriving in the condenser. In addition, the temperature in the turbine decreases by several tens of degrees. Thus, we see that the temperature to which the air is heated in an ATJEMC is 150 - 200° less than the temperature to which the working medium is heated in the reactor. In order to increase the temperature to which the air is heated, it is necessary to insert in its path downstream of the condenser, an additional heat exchanger through which the heat-transfer agent is forced directly from the reactor, bypassing the turbine. Several designs for ATJEMC are possible, using this type of supplementary heating. Two of these are shown in Figs.41 and 42.

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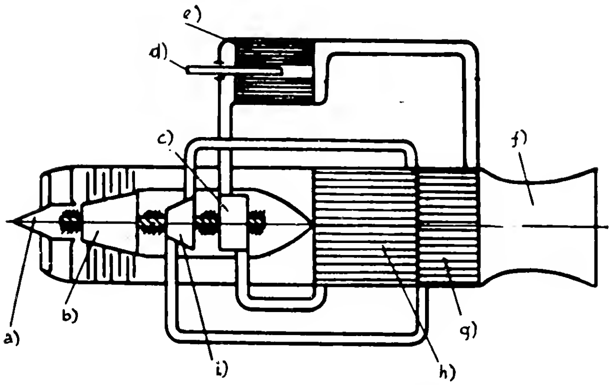

Fig.41 - Schematic Sketch of an Atomic Engine with Motor-Driven Compressor and Supplementary Heating

a) Nose cone; b) Compressor; c) Helium compressor; d) Control rod; e) Reactor; f) Jet nozzle; g) Auxiliary heat exchanger; h) Heat exchanger; i) Helium turbine

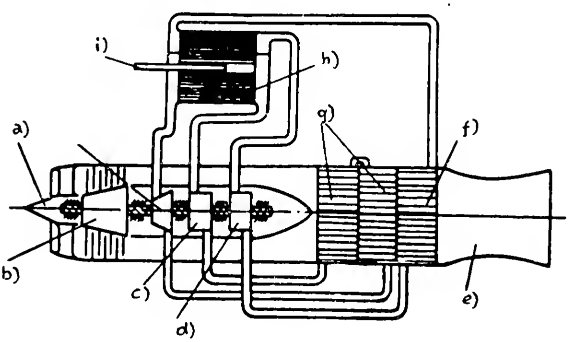

Fig.42 - Schematic Sketch of an Atomic Ram-Jet Engine with Motor Driven Compressor and Independent Circuit for Supplementary Heating

a) Nose cone; b) Air compressor; c) Helium compressor; d) Pump for heat-transfer agent; e) Jet nozzle; f) Auxiliary heat exchanger; g) Heat exchanger; h) Reactor; i) Control rod; j) Helium turbine

Figure 41 gives a sketch of an ATJEMC with one circuit for both working medium and heat-transfer agent. From the reactor, the helium proceeds to the auxiliary heat exchanger, then to the turbine and to the condenser, finally being recycled to the reactor by the compressor.

Figure 42 gives a sketch of an ATJEMC with two separate circuits, and with a reactor divided into two parts. The circuit for the working medium is the same as in the ATJEMC illustrated in Fig.40. The heat-transfer agent of the auxiliary circuit may be either gaseous or a liquid metal. The circulation of the gaseous heat-exchanger may be effected by a compressor, which is rotated by the main gas turbine or by a specially provided turbine. In the latter case, the turbocompressor of the auxiliary circuit may be installed independently of the engine. This results in a simpler design of installation of the entire power plant on the aircraft.

The use of helium as the working medium and as a heat-transfer agent for raising the operating temperature of the reactor opens broad vistas. If special chromium-nickel alloys are used as structural material for the reactor, the heating surface of the reactor may be increased to 1000 - 1100°C. At higher temperatures, the mechanical strength of these alloys is inadequate. The temperature of the heating surface of the reactor may be raised by another 200 - 300°C if molybdenum alloys are used. However, molybdenum combines readily with oxygen. Therefore, molybdenum heated to a high temperature must not be allowed to come into contact with air. If the molybdenum is surrounded by helium and inert gas, it will retain its mechanical strength for a long period at very high temperatures. If the temperature of the heating surface of the reactor is increased, the possibility exists to increase the temperature level of the entire power plant and, as a final result, to raise the temperature to which the air is heated, leading to an increase in engine thrust without the need of increasing its dimensions and weight.

If the temperature level of the entire power plant cannot be raised, then an increase in the temperature of the heating surface of the reactor will provide con-

siderable benefits in terms of size and weight of the reactor required. In designing a reactor for an aircraft power plant, its dimensions are determined on the basis of the required heating surface. This area will be smaller, the greater the temperature differential between the gas being heated and the heating surface. If the temperature of the gas being heated is taken as constant and if the temperature of the heating surface is increased, a reduction in the required heating surface area becomes possible and consequently a reduction in the dimensions of the reactor and its weight. This is exceedingly important for aircraft, since a reduction in flying weight at a power plant of identical capacity, results in improvement of the flight characteristics.

Let us discuss the power fluctuations in the turbine rotating the air compressor, with variations in flying speed. It was stated above that, in order for a gas turbine to operate in a closed cycle, a condenser must be installed between gas turbine and gas compressor. We know that the power of the gas compressor depends on the gas temperature. The lower the gas temperature at the compressor input, the smaller will be the required power of the gas compressor and the greater the excess power of the turbine which drives the air compressor. If the gas temperature at the input to the gas turbine is equal to the temperature of the gas at the turbine exit, the required power of the gas compreseor will equal the power of the gas turbine, and no excess power will be available at the air compressor drive. Thus, the condenser is an important link in a gas-turbine system. If the temperature to which the gas is heated in the reactor is regarded as constant, then the excess power of the gas turbine will be determined by the condenser, namely by the amount of heat dissipated from the gas in the condenser. This heat removed from the gas is used for heating the air passing through the ATJEMC. The amount of heat absorbed by the air, if we regard its thermal capacity as constant, depends on the temperature difference of the air and the gas and on the amount of air passing through the condenser.

From the theory of ram-jet engines we know that, as the flying speed increases, the air throughput of the engine per second also rises. At the same time, an increase also occurs in the temperature of the air at the engine input and, consequently, in the condenser. The temperature difference of gas and air in the condenser declines. Thus, two opposing factors act upon the amount of heat withdrawn from the gas. The increase in air consumption with increasing flying speed results in a greater dissipation of heat from the gas, while the decrease in temperature differential between air and gas tends to lower the dissipation. At low speeds the first factor predominates. Therefore, at the beginning, as the flying speed increases, the excess power of the gas turbine increases. Later, particularly at supersonic flying speeds, the second factor is predominant, and the excess power of the gas turbine decreases; there is also a drop in the compression ratio of the compressor. At the flying speed at which the temperature of the air at the condenser input becomes equal to the temperature of the gas at the turbine outlet, the turbine yields no excess power. The air compressor ceases to compress air, and the ATJEMC becomes an atomic ram-jet engine. The flying speed at which this "conversion" occurs is exceedingly high, several times that of sound. The resultant ARJE will develop thrust only if supplementary heating of the air is provided, i.e., only when engine designs such as those illustrated in Figs.41 and 42 are used. An aircraft with engines of the type shown in Figs.39 and 40, never attains the speed of "conversion" from ATJEMC to ARJE, due to the fact that at speeds below this level the ATJEMC ceases to develop thrust as a result of various types of losses.

Let us derive data for calculating aircraft power plants built around two ATJEMC serving a single reactor. Each atomic engine develops 20 tons of thrust at sea level. The engine has a helium turbine of 48,500 hp capacity, rotating an air compressor. The circulation of helium in the closed cycle is provided by a helium turbocompressor. The capacity of the turbine of the helium turbocompressor is 94,800 hp at a rated rotational speed of 16,000 rpm. The six-stage axial helium

compressor has a compression ratio of 2.1. The helium pressure at the compressor input is 25 atm and at the reactor input about 52 atm. The air compressor has two supersonic stages. At 5850 rpm, the compression ratio is 2.3. The air is heated by helium in a slot-type heat-exchanger, having 2520 m^2 heating surface. A total of 370 kg air passes through the heat-exchanger of each engine per second at sea-level operation.

The reactor is of the uranium-beryllium type, using intermediate neutrons. Its thermal capacity, under design operating conditions, is 490,000 kw. At this rate, the reactor consumes 21 gm $uranium^{235}$ per hour.

Atomic Turboprop Engines

Turboprop engines are used today primarily for heavy long-range aircraft flying at speeds close to the speed of sound. At subsonic speeds, turboprop engines are more economical than turbojets. Per kilogram of thrust, the former require consider-

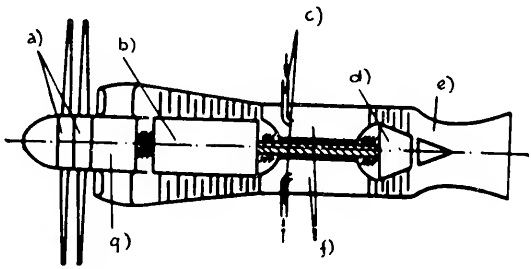

Fig.43 - Schematic Sketch of a Turboprop Engine

a) Propellers; b) Compressor; c) Kerosene injectors; d) Turbine;
e) Jet nozzle; f) Combustion chamber; g) Reduction gear

ably less kerosene per hour. Moreover, turboprop engines provide the best flight characteristics for aircraft: the length and time of the take-off run is reduced, and the rate of climb is increased. The design of turboprop engines (Fig.43) is

similar to that of a turbojet engine. The turbine in a turboprop engine is usually of the multistage type. Such a turbine is considerably more powerful than that of a turbojet having the same thrust. The excess thrust of the turboprop turbine over that used to rotate the compressor is consumed in rotating the propellers. Usually two coaxial propellers are rotated in opposite directions over a reduction gear. The bulk of the thrust is produced by the propellers. Only 10% - 15% is created by the reaction of the stream of gases ejected from the jet nozzle.

The use of atomic turboprop engines offers the simplest solution of the problem of vertical take-off and landing of aircraft. ATJE and ATJEMC engines eject powerful jets of highly heated air. This would require the provision of special exhaust ducts to prevent destruction of the runway surface. The aircraft remains dependent upon properly equipped landing strips. If the power plant of the aircraft consists of atomic turboprop engines, the streams of hot air will be only a fraction as intense and will mix with the cold slipstream of the propeller. This will permit landing on any level field with a hard surface.

However, the main advantage of atomic turboprop engines over atomic turbojet engines and ATJEMC is the fact that the former develop a take-off thrust 20% - 30% greater, with a reactor of identical power.

Atomic turboprop engines can be classified into two groups in terms of design. The first group comprises engines using air turbines and the second group includes engines using steam or gas turbines.

The design of engines in the first group is similar to that of the atomic turbojet engines illustrated in Figs.33, 36, and 37. The difference lies in the fact that in all atomic turboprop engine designs the turbine is not only connected to a compressor but also (over a reduction gear) to propellers. Figure 44 shows the design of a turboprop engine in this category. The air is sucked in by the compressor, compressed, and supplied to the reactor. In the reactor, the air is heated and delivered to the turbine, where it is rotated and then ejected through the jet

nozzle. The turbine rotates the compressor and the attached coaxial propellers.

It is also possible to develop atomic turboprop engines with two independent turbines, one rotating the compressor and the other the propellers. Figure 45 illustrates an atomic turboprop engine with two coaxial turbines. The front two-stage turbine is connected to the compressor by a hollow shaft, while the rear turbine is

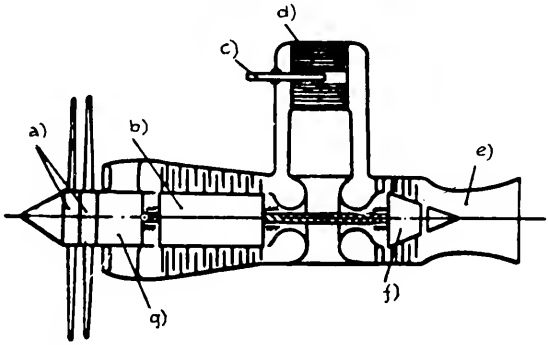

Fig.44 - Schematic Sketch of an Atomic Turboprop Engine with Separately Housed Reactor

a) Propellers; b) Air compressor; c) Control rod; d) Reactor; e) Jet nozzle; f) Air turbine; g) Reduction gear

connected to the reduction gear via a long shaft passing within the turbocompressor shaft. This method of making the turbocompressor a separate assembly should logically facilitate the control of the engine since the operating conditions of the turbocompressor and the propellers will be less interdependent under these circumstances. In the design of an atomic turboprop engine, illustrated in Fig.44, the rotational speed of the propellers and the compressor are interrelated, and any change in the rotational speed of the propellers will cause a change in that of the compressor, in the compression ratio of the air in the compressor, in the air throughput of the engine, and in the power of the turbine; this, in turn, will affect the rotational speed of the propellers.

Engines with steam or gas turbines may be categorized as forming a second group of atomic turboprop engines. Their design is similar to that of atomic ram-jet engines with motor-driven compressors, as illustrated in Figs.39 and 40. Figure 46

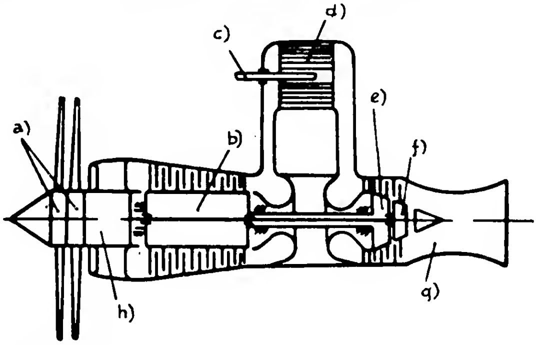

Fig.45 - Schematic Sketch of an Atomic Turboprop Engine with Separate Drives for Compressor and Propellers

a) Propellers; b) Air compressor; c) Control rod; d) Reactor; e) Air Turbine for compressor; f) Air turbine for propellers; g) Jet nozzle; h) Reduction gear

presents the design of an atomic turboprop engine with a mercury turbine. The mercury is heated in this engine by means of liquid sodium as the heat-transfer agent, which is circulated by a pump. The mercury vapors, produced in the heat exchanger, are delivered to the turbine. The energy of the mercury vapor is converted to mechanical energy in the turbine and is transmitted to the propellers by means of the reduction gear. The used vapor proceeds to a condenser and is there condensed to liquid mercury, which is recycled by pump to the heat exchanger. Heat is removed from the mercury vapor in the condenser by air forced through the condenser by a fan.

More than 90% of the thrust of an atomic turboprop engine with a steam turbine is created by the propellers. The thrust created by the reaction of the air passing

through the condenser is negligible, since the air is heated to a comparatively limited extent. However, the condenser of an atomic turboprop engine is essentially a ram-jet. Thus, the atomic turboprop engine with a steam turbine actually repre-

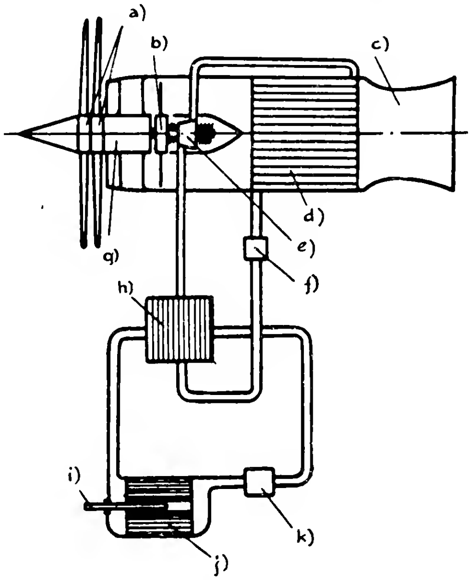

Fig.46 - Schematic Sketch of an Atomic Turboprop Engine with Intermediate Heat-Transfer Agent

a) Propellers; b) Fan; c) Jet nozzle; d) Condenser; e) Mercury turbine; f) Mercury pump; g) Reduction gear; h) Heat exchanger; i) Control rod; j) Reactor; k) Pump for heat-transfer agent

sents two engines: a turboprop, and a ram-jet. This combination is quite intriguing. Thus, a turboprop engine operates efficiently at low flying speeds, and a ram-jet at highspeeds. The problem is that of making proper and full use of the advantages of both types of engines. At low speeds, the main engine is the turboprop

and at high speeds, the ram-jet. In order to make more complete use of a turboprop engine, it is desirable to install an auxiliary heat exchanger in the path of the air downstream of the condenser, similar to that illustrated in Fig.42, and heat the air to the highest possible temperature. As the flying speed increases above a given level, the power of the steam turbine begins to drop due to a decrease in the dissipation of heat in the condenser, and the share of the propellers in the production of thrust begins to decline, while the share of the ram-jet engine starts to increase. At a flying speed only 50% greater than the speed of sound, the condenser and its auxiliary heat exchanger will develop one-half the thrust of the entire power plant, even if special supersonic propellers are used whose efficiency decreases only insignificantly with increasing flying speed. Thus, an atomic turboprop engine with steam turbine is capable of self-regulation. As the flying speed increases, there is a reduction in the power of the propellers accompanied by an increase in thrust of the ram-jet engine.

The above statements on self-regulation are also valid for the atomic turboprop engine using a gas turbine, whose design is presented in Fig.47.

However, as in the case of an ATJEMC, the gas turbine has to be several times as powerful as a steam turbine of equal power. The dimensions of the gas turbocompressor will be considerably greater than those of the mercury turbine and the mercury pump. The advantage of an atomic turboprop engine with gas turbine is the lack of the need for a heat exchanger and an intermediate heat-transfer agent, and the possibility of heating the gas directly in the reactor. This is no small advantage, since the presence of an intermediate heat-transfer agent significantly complicates the operation of an atomic power plant.

In order to increase the economy of modern power plants and engines using chemical fuels, wide use is made of what is known as heat recovery. The principle of heat recovery lies in the fact that a portion of the heat of the combustion product is utilized to heat the air entering the furnace.

Heat recovery may also be used in an atomic turboprop engine with a gas turbine. In addition to economizing nuclear fuel, heat recovery permits a significant reduction in the heat-exchange interface between working medium and air in the condenser.

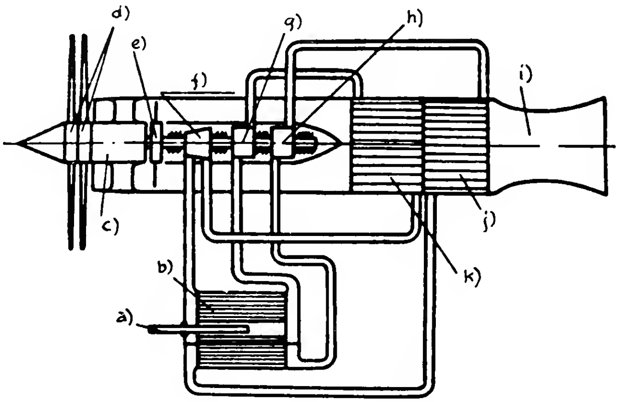

Fig.47 - Schematic Sketch of an Atomic Turboprop Engine with Independent Supplementary Heating Surface

a) Control rod; b) Reactor; c) Reduction gear; d) Propellers; e) Fan; f) Helium turbine; g) Helium compressor; h) Pump for heat-transfer agent; i) Jet nozzle; j) Auxiliary heat exchanger; k) Heat exchanger

Figure 48 gives a schematic sketch of a helium atomic turboprop engine with heat recovery. The helium from the turbine passes through the heat recovery unit, where it surrenders a portion of its heat to the helium, proceeding to the compressor from the reactor, and is then delivered to the condenser. The finally cooled helium is compressed in the compressor and delivered to the reactor. On the way to the reactor it undergoes preliminary heating in the recovery unit. Consequently, the consumption of nuclear fuel decreases, and the weight and size of the reactor may be reduced.

Thanks to the fact that the heat transfer in the recovery unit takes place from

helium to helium, the heat-exchanger surface in the recovery unit need only be a fraction of that which would be required to remove the same amount of heat from helium to air. As a result, the size and weight of the recovery unit can be relatively small.

When a recovery unit is present, the quantity of heat removed from helium to air in the condenser will decrease, so that the dimensions and weight of the con-

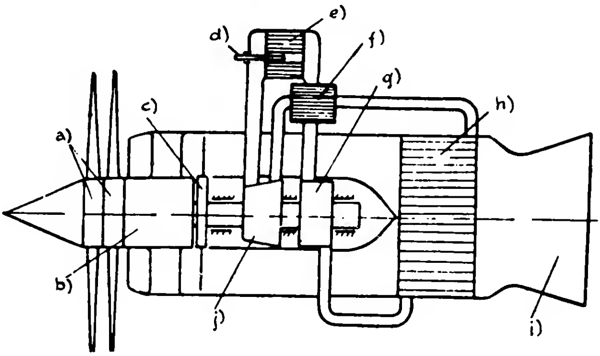

Fig.48 - Schematic Sketch of a Helium-Driven Atomic Turboprop Engine with Heat Recovery

a) Propellers; b) Reduction gear; c) Fan; d) Control rod; e) Reactor; f) Heat recovery unit; g) Helium compressor; h) Heat exchanger; i) Jet nozzle; j) Helium turbine

denser can also be reduced.

However, despite the above advantages, the use of heat recovery may be unprofitable. The point is that the temperature to which the air is heated in the condenser is reduced in the presence of a heat recovery unit. Consequently, the role of the condenser as a ram-jet engine is diminished.

Let us describe one more design of an atomic turboprop engine with a steam turbine using water vapor, produced in a "boiling-water" type of reactor. This design

is presented in Fig.49. The "boiling-water" reactor is a large vessel containing ordinary or heavy water, into which uranium rod lattice encased in aluminum or zirconium cans is inserted. If the rods are of natural uranium, heavy water has to be used; if the rod material is enriched uranium, ordinary water may be used. The

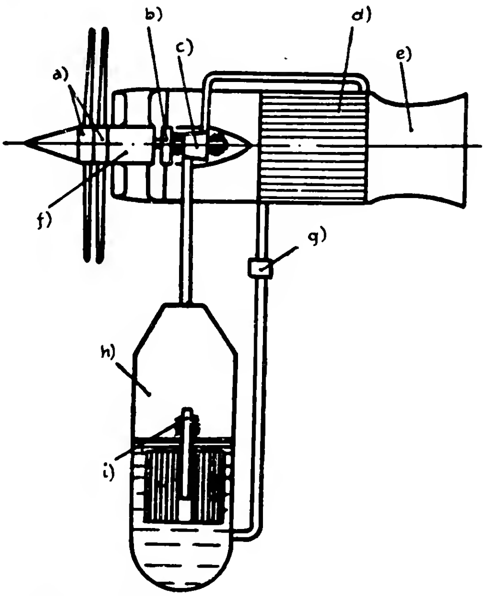

Fig.49 - Schematic Sketch of an Atomic Turboprop Engine with "Boiling-Water" Reactor

a) Propellers; b) Fan; c) Steam turbine; d) Condenser; e) Jet nozzle; f) Reduction gear; g) Water pump; h) Water reactor with steam separator; i) Control rod

water in the reactor acts as a moderator and, at the same time, serves to remove the heat from the uranium rods. The power level of the reactor is so regulated that the required amount of steam will be produced each second. The steam from the reactor

proceeds to the turbine which it rotates; the steam is then condensed in the condenser and is recycled to the reactor by pump. The power of the pump is about 2% of the power of the turbine. The turbine is connected to coaxial propellers as in the above-described design.

The advantages of this design are simplicity, reliability in operation, and its relatively low cost. A "boiling-water" reactor has a self-protection from explosion in case of breakdown if, for any reason the control rod mechanism fails. At the instant of excessive liberation of heat, the water is converted into steam which latter is discharged into the atmosphere through a safety valve. The reactor now no longer has a moderator, and any nuclear reaction instantly decays. To start the reactor again all that is needed is to refill it with water. It is easy to remove from the water the uranium fission products, which are very strong neutron absorbers. This makes it possible to reduce the reserve reactivity of the reactor and increase the percent "combustion" of nuclear fuel.

The shortcomings of this design are the radioactivity of the water passing through the turbine and the exceedingly low temperature of condensation of the water vapor. The latter prevents efficient use of the condenser as a ram-jet engine.

The reader has no doubt become aware by now that, in all above designs of atomic turboprop engines, a reduction gear is an essential component. The turbines of modern turboprop engines rotate at 6000 - 15,000 rpm. The high rotational speeds are necessary to hold down the dimensions of the high-power turbines. The propeller operates most effictively when it rotates at about 1000 rpm. Thus, the reduction gear serves the purpose of reducing the rpm to the level most advantageous for propeller operation.

If two propellers are mounted on the engine, the reduction gear has the additional function of changing the direction of rotation of one of the propellers so that they will rotate in opposite directions. This also increases the efficiency of the propellers. Difficulties with the reduction gear are among the major causes for

the limited usefulness of turboprop engines in modern aircraft. At present, transmissions with involute teeth are in wide use in reduction gears. There are many shortcomings inherent in this system (low contact strength, sensitivity to lack of precision in manufacture and assembly, high friction losses leading to overheating of the gears, etc.). The lightest and most reliable type of reduction gear is that used in marine power plants. The weight of such reduction gear is about 1 kg per horsepower transmitted. The weight of modern aircraft reduction gears is 7 - 10 times lower. This saving in weight is obtained at the expense of a sharp reduction in the service life of the gear. But even this weight level is excessive for aircraft. Even if only 0.1 kg of reduction gear weight is required per transmitted horsepower, the total weight of the transmission, for a 50,000 hp engine will be 5 tons, and powers of 50,000 - 100,000 hp will be customary for atomic power plants. Designers and scientists of all countries are making every attempt to reduce the weight of the reduction gear. There is reason to hope that, in the very near future, the gearing invented by N.L.Novikov, will provide a means for increasing the power transmitted by reduction gears without increasing their weight.

However, it would be desirable to completely eliminate the use of a reduction gear. Is this possible? Calculations show that a reduction gear may be eliminated completely if a mercury turbine is used. The possibility exists of designing a turbine in which the rotor will rotate in one direction and the housing in another. The rotor will be connected by shaft to the tractor propeller and the housing will be connected to the pusher propeller over a hollow shaft which contains the second shaft. If the rotational speed of the rotor relative to the housing is 4000 rpm, then each propeller will rotate at 2000 rpm. This rpm is satisfactory for specially-designed supersonic propellers. The design difficulties encountered in creating such an engine without reduction gear will, of course, result in an increase in turbine weight, but this increase in weight will be only a fraction of the weight of a reduction gear.

Let us give an example of the project of an atomic aircraft power plant consisting of two atomic turboprop engines without reduction gear and using mercury turbines. Mercury vapor, heated to a temperature of 800°C is delivered to the six-stage turbines of 70,000 hp each, at a pressure of 112 atm. The mercury vapor is produced in a fast-neutron reactor. The power of each turbine is distributed between two coaxial propellers (60,000 hp), with the fan forcing the air through the condenser (9000 hp) and the pump recycling the liquid mercury to the reactor (1000 hp). The weight of the entire power plant will be 20.5 tons. Of this, the weight of the two engines is 11.2 tons, the dry weight of the reactor (without shielding) is 4.5 tons, and the weight of the mercury is 4.3 tons. At a flying weight of 85 tons, an aircraft with this type of atomic power plant will be able to carry 3 tons of useful load and fly at a speed 2.5 times that of sound. The consumption of nuclear fuel under these conditions will be 13 gm/hr.

Combination Power Plants with Nuclear and Chemical Fuels

We have already discussed the difficulties of designing a high-temperature reactor, the difficulties of shielding the aircraft from the reactor radiations, and the lack of a clearly defined method for overcoming these difficulties. The general trend to travel a blazed trail has resulted in the appearance in the press of opinions to the effect that the first atomic power plants will include not only atomic, but also conventional engines, and that after the air is heated in the reactor, it will be heated further by the combustion of kerosene or gasoline in this air.

Underlying some of the suggestions for the development of power plants, including both atomic and conventional engines to function throughout the flight, is the effort to reduce the capacity of the reactor so as to lower the dimensions and weight both of the reactor itself and of the radiation shielding. Other suggestions along these lines are based on the effort to use an atomic engine as the main source of energy and to connect the conventional engine whenever necessary for a brief

period in order to increase the power of the power plant, as for example, during take-off, climb, etc. Let us see what the real possibilities of such proposals might be.

The compound power plant and its radiation shielding can make use of that portion of the total weight of the aircraft which is ordinarily taken up by the conventional power plant and its fuel reserve in present-day aircraft. If a conventional engine is retained in the compound installation, then the atomic engine and its radiation shielding can be installed on the aircraft only at the expense of the fuel reserve, with the provision that a portion of this reserve must be set aside for operating the conventional engines. This portion is so small that the possible operating time of the conventional engine may be calculated in minutes. If this fuel residue is divided by the entire period of flight, the thrust of the conventional engines would have to be so small that no noticeable improvement in the flight characteristics of the aircraft could be expected from this operation. Thus, a compound power plant, consisting of atomic and conventional engines, can hardly be considered realizable and is obviously not rational.

However, it is possible to combine the use of nuclear and chemical energy in a single engine. Figure 50 illustrates an engine of this type. This is an atomic turbojet engine in which the air is heated in a separately housed reactor. Then kerosene is injected into the air and, on combustion, heats the air further. If this engine would use a turbine with cooled blades, the temperature of the air upstream of the turbine could be raised to 1500°C. This will result in increasing the specific and frontal thrust and in reducing the engine weight. If the engine is limited to standard temperatures ahead of the turbine (of the order of 800°C), then in an engine built according to the design shown in Fig.50, the temperature of the heating surface of the reactor can be reduced compared to that of the heating surface of the reactor in a regular atomic turbojet engine. It will be easier to design this type of reactor. This is the point generally emphasized in statements to

the effect that combination systems will be developed before purely atomic systems. However, it is quite doubtful whether the range of flight with such a combination engine will exceed the range of an aircraft with conventional engines of today. They may, however, serve as experimental installations for gathering experience in the operation of power plants with nuclear reactors.

It is much more probable that atomic jet engines with kerosene afterburners

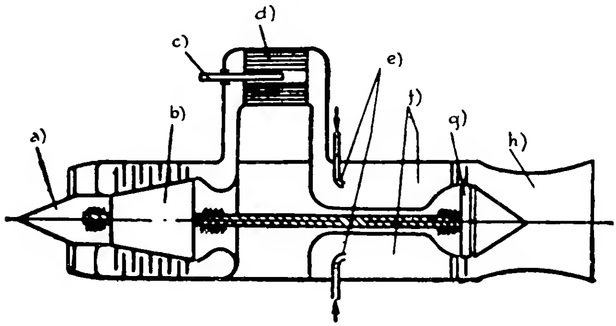

Fig.50 - Schematic Sketch of a Combination Turbojet Engine Using Nuclear and Chemical Fuels

a) Nose cone; b) Compressor; c) Control rod; d) Reactor; e) Kerosene injectors; f) Combustion chamber; g) Turbine; h) Jet nozzle

will come into practical use. Such engines will have a standard afterburner chamber between the turbine and the jet nozzle. In this chamber the air will undergo supplementary heating by combustion of kerosene. The afterburner chamber will be turned on for brief periods: on take-off, in climb, during acceleration, and for brief boosts of maximum flying speed. Atomic turbojet engines with afterburners will first be used in military aircraft so as to provide air superiority in tactical flight characteristics. In passenger and transport aircraft, it might be more desirable to save the weight of kerosene required for such boosters, in favor of increasing the payload, the number of passengers to be carried, etc.; in addition,

the possibility of improving the tactical flight characteristics of a given aircraft by increasing the power of the atomic power plant itself should not be forgotten. If a more powerful atomic turbojet engine were installed on an aircraft, whose weight would equal that of an atomic jet engine with booster and supplementary fuel, it could well be that the thrust would be no less than that of the atomic jet engine with its booster operating. If this proves to be the case, it is obvious that there will be no gain by using an atomic turbojet engine and booster.

From the above statements on combination power plants, it would follow that their application, if at all, will be only for experimental purposes.

Probable Designs of Atomic Power Plants for Aircraft

The basic shortcoming of all atomic ram-jet engines is the very method of heating air in the engine by heat-transfer from the heating surface of the reactor or the heat exchanger. In the first place, this method of heating results in increased friction losses. In the second place, the heating of the air by heat transfer requires a temperature of the heating surface at least 50° - 100°C higher than the temperature of the already hot air. When kerosene is burned in conventional engines, the liberation of heat occurs throughout the entire volume of the combustion chamber, and the temperature of the combustion products is usually considerably higher than the temperature of the combustion-chamber walls, cooled by forced currents of cold air.

We know that the mechanical strength of metals is reduced at increasing temperatures. If the structural materials of the reactor and the combustion chamber can withstand equally high temperatures, the temperature to which the air has to be heated in an atomic engine will be less than in a conventional engine, which along with the increased friction losses, will result in a reduction in the specific thrust of the engine, and in an increase in its specific weight. Thus, the very principle of transferring heat to air by heat liberation in atomic engines faces the

problem of lower specific parameters than those in conventional jet engines. Now, if we could only cause the heating to take place throughout the entire volume of the air instead of only in a thin layer adjacent to the heating surface!

Let us examine a design of an atomic ram-jet engine, as illustrated in Fig.51. A gaseous, liquid, or powdered nuclear fuel is injected into the air, compressed by the velocity head. On entering the reactor chamber, this nuclear fuel is subjected to the effects of a neutron flux, with a result that a portion of the nuclei under-

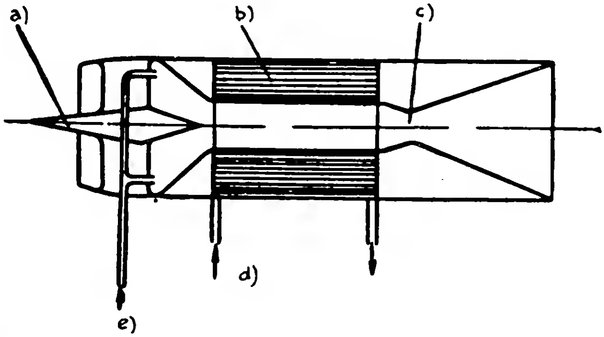

Fig.51 - Schematic Sketch of an Atomic Ram-Jet Engine with Gaseous Nuclear Fuel

a) Nose cone; b) Reactor; c) Jet nozzle; d) Reactor cooling; e) Gaseous nuclear fuel

goes fission. In this case, the liberation of heat occurs throughout the entire volume of air, with the result that the contact area between air and reactor can be reduced by hundreds of times. This leads to a significant reduction in friction losses. Heated air, as before, enters the jet nozzle, and is ejected at high velocity.

The function of the reactor in this design is different from that in all atomic engine designs we have discussed up to now. There the reactor was a source of heat, here the reactor is used as a neutron source. However, the production of neutrons

during the nuclear reaction is accompanied by the liberation of large quantities of heat. A heat-transfer agent must be circulated through the reactor in order to dissipate this heat. The heat removed from the reactor may be used for operating a steam or gas turbine of another engine or for heating air in an atomic turbojet engine heat exchanger, used in combination with the atomic ram-jets discussed above.

An analysis of the practicability of the engine illustrated in Fig.51, shows that the decisive factor is the high concentration of nuclear fuel injected into the air, i.e., in the final analysis, a large rate of consumption of this fuel. Moreover, in order to increase the probability that neutrons will collide with fuel nuclei, the density of the neutron flux must be considerably increased. To attain the necessary rates of consumption of the injected nuclear fuel, it is necessary, as we learn from calculations, to increase the density of the neutron flux of the reactor by thousands and hundreds of thousands of times, relative to the maximum attained to this date in stationary systems. An increase in the density of the neutron flux will, in turn, lead to an increase in heat liberation in the reactor itself which will require a higher rate of heat dissipation, etc. All of this makes realization of the design in Fig.51 improbable.

If it is impossible at present to solve the problem of attaining a high density of neutron flux, might it not be possible to provide for trapping the powdered nuclear fuel? An atomic turbojet engine operating on this principle is illustrated in Fig.52. Into air compressed by the compressor, a mixture of powdered atomic fuel and air is injected (or taken in by suction). The nuclear fuel is more or less uniformly mixed with the air and enters the channels honeycombing the reactor. It is here that the nuclear reaction occurs and the air is heated, from where it enters the turbine which in turn rotates the compressor. From the turbine the air emerges in a spiral stream, rotating about the axis of the engine. The heavy particles of nuclear fuel are hurled toward the outer surface and are sucked out along with a small quantity of air, again to be mixed with the air at the reactor input.

Certain authors propose a complete elimination of a reactor in the conventional meaning of the term. They propose that atomized nuclear fuel be introduced at the compressor input. In the air compressed by the compressor, the concentration of nuclear fuel increases; as soon as this air enters a duct surrounded by a neutron reflector, a nuclear reaction is initiated and the air is heated. Downstream of the

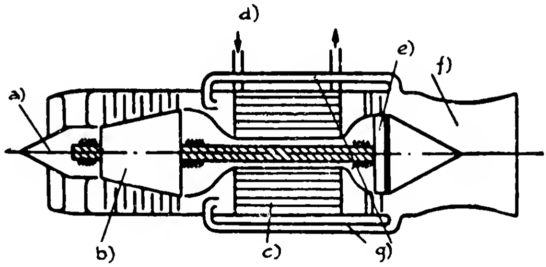

Fig.52 - Schematic Sketch of an Atomic Turbojet Engine with Atomized Nuclear Fuel

a) Nose cone; b) Compressor; c) Reactor; d) Reactor cooling; e) Turbine; f) Jet nozzle; g) Duct for recycling the atomized nuclear fuel

turbine, the nuclear fuel is trapped, as in the engine (Fig.52). The cooling of the reflector is much easier for the cooling of the reactor. However, the realizability of such a design is rather dubious. The dimensions of the duct in the reflector must be quite large in order for a nondecaying nuclear reaction to occur in the nuclear fuel, atomized in the air. As the concentration of nuclear fuel in the air increases, the dimensions of the channel may be reduced. However, this would lead to a decrease in engine thrust, due to the fact that an excessively large share of the air will be tapped downstream of the turbine, along with the nuclear fuel. An increase in concentration by increasing the compression ratio of the compressor is not possible above a fixed level since, in the course of compression, the air be-

comes heated and may reach the maximum temperature permissible for strength considerations. Thereafter, further heating becomes impossible, so that the turbine will be unable to rotate the compressor, not to mention the fact that the engine will develop no thrust.

There have been proposals to heat the air in the engine by an electric arc. However, this method of air heating has its drawbacks. For example, it is difficult to develop a reliable electric arc of such extraordinary power, that will function for the relatively long period during which the engine is expected to operate without interruption. In addition, the system for producing electric energy will be bulky and heavy and most likely will cancel the gain obtained by the absence of a heat exchanger.

Vast perspectives will open before the aircraft designer when science is able to control thermonuclear reactions. The rapid development of nuclear physics in recent years testifies to the fact that the major difficulties in creating a controlled thermonuclear reaction will be overcome and a thermonuclear engine will be developed. The application of thermonuclear engines to aviation will result in further advancement in aircraft design, and will make aircraft less earth-bound, enabling it to fly in the upper layers of the atmosphere at colossal speeds.

CHAPTER IV

AIRCRAFT WITH ATOMIC ENGINES

The Problem of Radiation Shielding

The development of aircraft with atomic engines involves the necessity of overcoming the radiation hazards due to the emission of various types of radiation having a detrimental effect upon the human organism.

The first concepts as to radiation hazards and the difficulties of shielding human beings from the radiations of atomic engines appeared simultaneously with the first ideas on atomic aircraft. As far back as the beginning of 1935, the Soviet scientist, O.Petrovskiy, advanced the idea of an atomic train of stratoships (Figure 53), in which the protection of the passengers from the effects of radiation would be attained by housing the crew and passengers at a considerable distance from the atomic, or subatomic, engine. These ideas, advanced more than twenty years ago, are still of interest today. Therefore, we will quote an excerpt from O.Petrovskiy's article* in which he discusses an atomic train of stratoliners: "This train will consist of two units. The first travels, as a rule, without human beings aboard and is equipped with subatomic engines. This unit will tow a second aircraft by means of cables approximately 1000 m in length. The second aircraft will be designed, more or less, along the lines of a glider without engines. Con-

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* The article "An Isotope Gun" was published in the journal Tekhnika Molodezhi (Technics for Youth), No.1, January 1935.

trol will be exerted from this second aircraft.

"The reason for the separation of this stratoplane train into two separate machines is chiefly the fact that the powerful radioactive decay in the engine is ac-

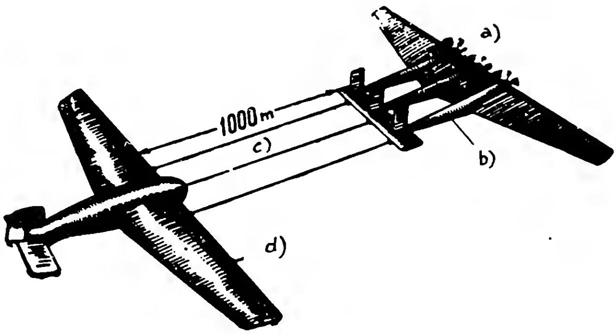

Fig.53 - Schematic Sketch of an Atomic Train of Stratoplanes from the Journal "Tekhnika Molodezhi", No.1, 1935

The train of stratoplanes with subatomic engines will consist of two units. The subatomic engines will be installed on the first, while crew and control mechanism will be carried on the second.

a) Engine stratoplane (no crew); b) Fuselage with groups of isotope guns; c) Towing cables of 1000 m length; d) Engineless stratoglider with crew (towed by cable)

companied by a no less powerful radiation.

"For protection from this radiation, which is extremely harmful to the human organism, no means other than removal to a considerable distance exist at present."

Today, the problem of protection from radiation by other means, for example shields, is no longer as hopeless as it had been then; however, even now this is

one of the most complex problems in the development of atomic aircraft equipped to carry human beings. During the last 10 - 15 years, scientists have made a careful study of the properties of various types of radiation produced in the operation of atomic power plants, and have discovered the most effective materials for shields. They have also developed the basic principles for shielding systems. Let us briefly treat these problems:

The radiation emitted during the operation of atomic power plants include the following that are harmful to the human organism: alpha rays, beta rays, gamma rays, and neutrons.

Alpha Rays represent a stream of positively charged particles: helium nuclei. Their penetrating power is quite insignificant. In air, for example, they travel no more than 10 cm from the radiation source and in metals only hundredths of a millimeter. Virtually the sole source of alpha particles in an atomic power plant is the nuclear fuel (uranium and plutonium), which is naturally radioactive. Alpha particles are completely absorbed in the metal cans in which nuclear fuel is usually encased and, therefore, require no further consideration on our part.

Beta Rays represent a stream of electrons. The major source of beta radiation are the fission "fragments" of the fuel nuclei. Emission of beta rays also results from the absorption of neutrons by nuclei of most of the chemical elements comprising the moderator, the heat-transfer agents, the structural materials, other materials used. The penetrating power of beta rays is greater than that of alpha rays, but still comparatively small; in air, beta particles can travel up to 20 m and in metals a few millimeters.

Gamma Rays are an electromagnetic radiation similar to x-rays but of shorter wavelength. About 95% of the total flux of gamma rays emitted by a reactor is due to fission of the fuel nuclei. In addition, such rays are generated on absorption of neutrons by the nuclei of certain chemical elements that go into the makeup of a nuclear reactor.

Neutrons are particles of neutral charge, representing a constituent of atomic nuclei. These are emitted on fission of the fuel nuclei. The absence of an electric charge explains their high penetrating power. Fast neutrons have an exceptionally high penetrating power. The absorption of neutrons by nuclei usually results in artificial or induced radioactivity. In other words the nuclei of a majority of elements themselves become sources of radioactive radiation as they absorb neutrons.

The above types of radiation cause a specific disease in man: radiation sickness. The degree of damage to the organism depends upon the quantity of radiant energy absorbed or, as it is called, the radiation dose. The magnitude of the dose received is greater, the greater the intensity of radiation and the longer the time during which the human being is exposed. A special unit called the roentgen is used for measuring the size of the dose.

A single irradiation at a dose of up to 50 roentgens produces no observable changes in the human organism, and the subjective feeling of well-being is no way impaired. A dose of 50 - 100 roentgens induces insignificant changes in the blood, which rapidly disappear without leaving a trace.

If irradiation is repeated periodically, then even at a small daily dose radiation sickness may occur since the effect of radiation is cumulative. At present, it is believed that the maximum dose for a human being daily exposed to irradiation over a period of years should not exceed 0.3 roentgen.

The main source of radiation in an atomic aircraft is the nuclear reactor. The intensity of radiation is greater, the greater the power of the reactor. When the reactor is turned off, the intensity of radiation diminishes greatly, but a rather significant radiation continues for a long period, since certain artificially radioactive substances formed during operation of the reactor decay very slowly.

Special shelters and shields are only necessary for biological protection from gamma radiation and neutrons. In view of the small penetrating power of beta rays,

these will be absorbed completely in the shields.

In view of the fact that gamma rays react primarily with electrons, the best shielding material is a substance with a large number of electrons per atom. Iron, steel, lead, and bismuth find practical application as materials capable of weakening the flow of gamma rays. As a rule, the greater the density of the substance, the smaller will be the thickness of the layer of substance required for obtaining a given reduction in the intensity of gamma radiation. For example, in order to reduce the intensity of gamma radiation by one-half, a layer of steel of about 2 cm thickness is required. The thickness of a layer of lead for the same purpose is 1.3 cm.

The neutron flux of a reactor includes neutrons of widely varying energies: from thermal to fast neutrons. Since high-energy neutrons are weakly absorbed by various materials, one of the main functions of neutron shielding is to retard these neutrons. In practice, protection from neutrons may take the form either of single-layer or double-layer shields. When using a two-layer shield, the first shield facing away from the reactor is made of a good moderator, and the second of a good absorber of neutrons. Minimum shield thickness is obtained when ordinary water is used as the moderator. However, the use of water for shielding an aircraft reactor is hardly within the realm of possibilities. In terms of operational realities, the best moderator for neutron protection aboard an aircraft is graphite. Graphite, however, has a drawback of its own: The thickness and weight of the protective shield is greater than for water.

If the shield is of a single layer, its structural material must simultaneously be able to moderate and absorb neutrons. To accomplish this end, the reactors of stationary power plants are surrounded by thick layers of ordinary water and concrete, with graphite or boron added. To improve the shielding qualities of the concrete, the water content in the cement mix is sometimes increased and added cadmium or boron is used, or graphite with added boron, or even pure boron. If

pure boron is used, the shield is thinner and lighter than a concrete shield or a shield in which graphite is used.

The difficulties in developing an atomic aircraft, with respect to radiation hazards, lie in the fact that even if the best materials presently known are used for shielding purposes, the weight and dimensions of the shield are quite considerable. The distances to which the crew and passenger quarters can be removed from the reactor in an aircraft is comparatively small and, for practical purposes, not more than 20 - 30 m. In this connection, a considerable portion of the required degree of moderation of the reactor radiation is taken up by the protective shields. When an aircraft reactor is operating at maximum output, the shields must reduce the intensity of radiation by a factor of 10 million. To reduce the intensity of gamma radiation by a factor of 10 million we need a lead shield of approximately 35 cm thickness. The weight of one square meter of such a shield is four tons.

The American scientist, R.Murray (Bibl.14), in an investigation of several possibilities of application of atomic energy in aviation, gave, as a typical example, the calculation of a shield for the B-47 bomber if that aircraft were to be equipped with atomic engines. The purpose of the calculation was to show the relationship between the weight of the shield and the payload of the aircraft for a given condition of flight: altitude 11 km, speed 800 km/hr. The initial weight data of the aircraft were as follows: empty weight, 62.5 tons; weight with conventional fuel plus payload, 92.5 tons. In order to attain these flight characteristics, the engine has to develop a total thrust of about 6.4 tons which, at a speed of 800 km/hr, corresponds to an engine power of about 18,000 hp. If it is considered that the total efficiency of an atomic power plant is 15%, then the thermal power of the nuclear reactor required would be approximately 90,000 kw, or 120,000 hp. Protection from gamma radiation and neutrons, as suggested by the author, would take the form of two spherical shields: the first of lead and the second of water. The diameter of the nuclear reactor, spherical in shape, would be

0.9 m. When the reactor is removed 15 m from the crew quarters, the necessary thickness of the lead shield will be 35 cm and that of the water shield 1.67 m. The total weight of such a shield (total weight of lead and water) was calculated as 172.5 tons, i.e., greater than the total flying weight of the aircraft.

In the next stage of his calculations, the author no longer used a closed spherical shell as basis. He now proposed a shield in the form of a sector of a sphere, placed between the reactor and the cockpit, and weighing only one fifth as much as a complete sphere, i.e., 34.5 tons. Using a reactor weight of 7 tons as basis, the author arrives at a flying weight of the aircraft of 104 tons, i.e., 12% greater than the normal flying weight of a B-47. If the flying weight is increased, the required conditions of flight, necessitate an increase in engine thrust and thus in reactor power. This, in turn, involves an increase in the weight of the shielding. On the basis of these calculations, the author draws the conclusion that "A vicious circle is thus created: The increased weight of the shielding requires an increase in engine power, and an increase in power requires an increase in weight of the shielding, and so forth".

We are not in agreement with this disoriented kind of conclusion. If the author had carried his calculations slightly further, he would have become convinced that in reality no "vicious circle" exists at all. An increase in flying weight by 12% certainly does require an increase in the reactor power and consequently an increase in the weight of the shielding. However, Murray's own calculations show that the weight of the neutron-radiation shielding increases by approximately one ton, i.e., by about 3% relative to its previous weight. Let us assume that we have increased the weight of the shielding by one ton. Then the flying weight of the aircraft will increase by that same sum. However, this increase is now only 1% and requires (in view of a certain increase in the necessary reactor power) an increase in the weight of the neutron shielding by only two or three tenths of a percent. Analogous results are obtained by calculation of

shields for gamma radiation.

The simplest calculations will show that, at any required condition of flight, the relative weight of the shielding system decreases with increasing flying weight. Reliable shielding from radiation in atomic aircraft, not inferior in speed and ceiling to the best modern aircraft using chemical fuel engines, is completely realizable. It is true that, for the present methods of radiation shielding, this will hold only for the heaviest types of aircraft, whose all-up weight is not less than 100 - 120 tons.

It would be advantageous if it were possible to design a shielding system as suggested by Murray, i.e., to place both shields only on one side of the reactor. In reality, the matter is somewhat more complicated. In order to reduce the neutron radiation, the reactor must be encased in shields on all sides. Otherwise, the structural materials of the aircraft, adjacent to the unshielded portions of the reactor, will be permeated by a powerful neutron flux. The degree of induced radioactivity will be so great that it will be impossible to approach the aircraft for long periods, even after the reactor has been removed. True, the weight of the shell on the sides of the reactor not directly facing the crew quarters can be reduced by making this portion of the shell thinner.

The shell, while reducing the intensity of neutron radiation to a nondangerous level, will not reduce the gamma-ray flux to the required degree. For protection from gamma radiation, a supplementary steel or lead shield is required. To do this in the form of a closed shell around the reactor is not believed possible because of the excessive weight that would result. Protection from gamma radiation can only be a partial or, as it is sometimes termed, shadow protection. The protective shield is mounted only on the side of the reactor directly facing the cockpit. Since the gamma rays will for the most part, move in straight lines, the location of the crew and passengers on an atomic aircraft will be within the shell, as it were. Except for a small spherical sector, all the remaining space around the re-

actor will be permeated by a gamma-ray flux of high intensity. Presence of human beings near an atomic aircraft while the nuclear reactor is operating and for a long

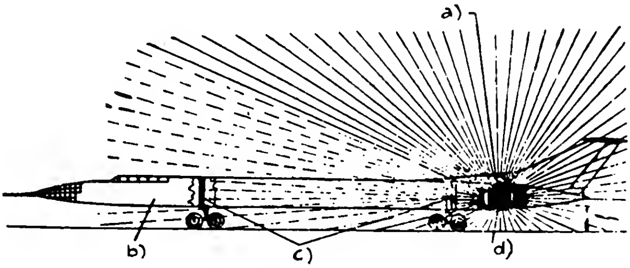

Fig.54 - Schematic Sketch of "Shell" Shielding of Passengers and Crew of an Atomic Aircraft

a) Neutron shield; b) Safe zone; c) Gamma-ray shields; d) Reactor

time thereafter will be impossible.

Figure 54 gives a schematic sketch of one of the variants of reactor shielding within the fuselage of an aircraft. The region of very high-intensity radiation is shown by solid lines, while the broken lines indicate the region with somewhat reduced intensity due to the first shield; however, only past the second shield do we find a danger-free zone for human beings during the entire flight.

It should be noted that the need for heavy shields is eliminated for the case of single pilotless devices, to be used only once i.e., long-range rockets, flying bombs, and radio-controlled bombers. The tendency to convert to pilotless means of aerial warfare exists today, independent of the introduction of atomic aircraft engines. Once atomic engines are produced, this tendency will become even stronger, since the problem of protection from radiation in unmanned devices consists primarily in a protection of ground personnel, so that the specific weight of an atomic

power plant relative to the total weight of the object can be considerably reduced.

Recently, proposals with calculations appeared, for transport or passenger aircraft with atomic engines: aircraft to be used for peaceful purposes. It is true that the design of biological shielding for passenger-carrying atomic aircraft is an even more difficult problem than for military aircraft. The weight of the shielding would be excessive, on the basis of the first approximate calculations. For example, for a passenger aircraft with a 15-ton payload, approximate calculations show that shielding of about 100 tons weight is needed to protect the passengers and crew from radiation. Shielding of this weight, quite obviously, will tip the scales against atomic aircraft. At one time, the thought was advanced that an atomic aircraft would become possible only when the total weight of the engine and the reactor plus the shielding would be less or equal to the weight of conventional aircraft engines plus the full load of chemical fuel (kerosene or gasoline).

This type of ratio is attainable only for the heaviest types of aircraft with an all-up weight of 120 - 200 tons, in which the weight of the engines and fuel would be 60 - 140 tons. It is already possible today to think of a combined weight of reactor, power plant, and shielding that would be in this weight category. In addition it should be remembered that, in view of the enormous advantage of atomic aircraft in terms of range of flight, a minor impairment in flying characteristics of the first atomic aircraft compared to conventional aircraft is entirely permissible. Even at reduced speed and ceiling and tolerating a certain excessive weight of the atomic power plant, the atomic aircraft will have certain indisputable advantages over conventional aircraft with respect to range of flight.

Special Design Features of Aircraft with Atomic Engines

To describe a design of atomic aircraft actually in existence is impossible since no such aircraft exists. But both in the press of our and other countries, a series of proposals as to design and general layout of a passenger-carrying

atomic aircraft has already been published. The major concern has been that of reliable protection of crew and passengers.

In the first place, considering that the intensity of direct gamma radiation from the reactor declines in inverse proportion to the square of the distance therefrom, the tendency is to move the reactor as far as possible from the passenger com-

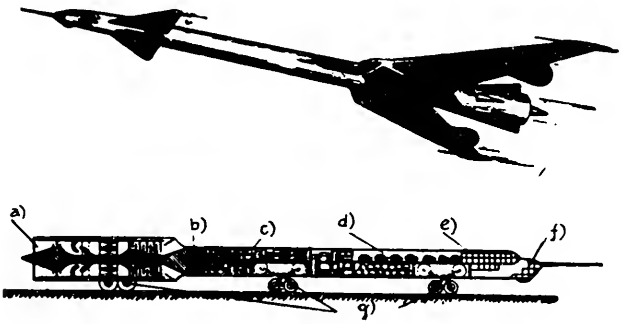

Fig.55 - Canard-Type Atomic Passenger Aircraft

a) Atomic power plant; b) Shieldings; c) Cargo; d) Trucks; e) Passengers; f) Crew; g) Landing gear

partment. For example, it is proposed to place the reactor in the tail of the fuselage or at the wing tips. Such a location of the reactor would compel a change in design and even in the conventional external shape of an aircraft.

In 1955, Professor G.I.Pokrovskiy proposed to design an atomic passenger aircraft of rather unusual appearance (Fig.55). The aircraft would have an exceptionally long fuselage whose tail section would contain the atomic engine, while the passenger compartment would be carried far forward. The abandonment of the conventional design with rearward location of the empennage is due to the fact that an atomic power plant represents a highly concentrated weight which should be as close

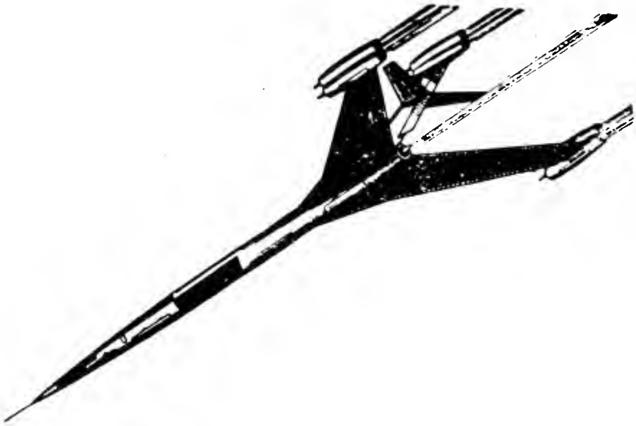

Fig.56 - Possible Variant of Atomic Transport Aircraft

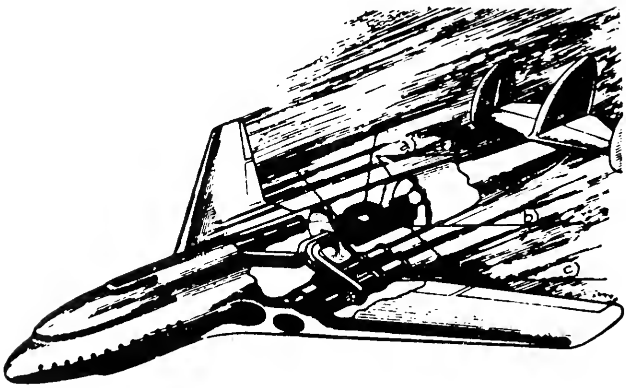

Fig.57 - Proposed Variant of Atomic Aircraft with a Single Reactor and Spherical Radiation Protection

a) Shielding; b) Reactor; c) Engines

to the center of the fuselage as possible. When shifted to the rear, this concentrated weight disrupts the aerodynamic balance, and the aircraft, with the center of gravity shifted to the rear, will tend to point its nose upward or, as the phrase goes, will pitch. Moreover the tail assembly of such an aircraft would be close to the center of gravity, the cables by which the aerodynamic forces of the controls are applied would be short, and the controls would have little effect. In order to eliminate these undesirable phenomena, G.I.Pokrovskiy proposed instead to use the canard design of aircraft, i.e., one in which the control surfaces are forward of the wing, since he believed this design best suited to the proposed purpose.

Interest in this type of design of an atomic aircraft has been displayed both here and abroad. However, certain doubts have been raised. The canard design was used in the early days of aircraft and was abandoned because of difficulties with the controls: an aircraft with its control surfaces forward of the wing has inadequate stability and is difficult to control on take-off and landing. The possibility is not excluded that, as time passes, the difficulties will be overcome and some atomic aircraft will adopt the canard design. There has been a story in the press to the effect that a canard-type aircraft has already been planned in England.

Another variant of atomic passenger aircraft design (Fig.56) envisages the placement of the engines in the wing tips and vertical tail surfaces. In this case, the general design is very similar to that of conventional aircraft, except that the engines are also carried far back, at the greatest possible distance from the passenger cabin. The stability of such an aircraft may be better, but the removal of heavy atomic engines from the center of gravity and placing them on long thin wing cantilevers and on the control surfaces raises doubt as to the reliability of the entire design.

The question as to which arrangement of the power plant is the more desirable has not yet been answered. Some designers believe that it is best to have one single reactor for all engines and to place it as close as possible to the center of

gravity of the aircraft, as illustrated in Fig.57. In this variant, it is easier to provide shielding for both passengers and ground personnel. In addition, the major concentrated load (reactor plus shielding) is in a more desirable location as far as stability and controllability are concerned. The shortcoming of this variant is the large weight of the all-around shielding of the reactor.

The weight factor in an atomic aircraft would be improved if the gamma-ray were designed not as a single shield but as a number of separate shields (Fig.58).

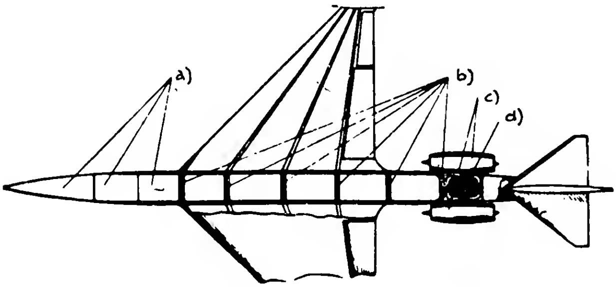

Fig.58 - Method for Incorporating the Shielding System in the Stress Pattern of the Aircraft

a) Compartments; b) Shielding; c) Engines; d) Reactor

It would be desirable to arrange the shielding material so as to be of greatest benefit to the design, permitting optimum balance of the aircraft and minimum stress on the stressed members of the glider. This would make it possible to use lighter shielding while providing adequate protection to the crew, to avoid excessive point loads, and to compel the shielding material to function in conjunction with the other stressed elements of the aircraft structure. It is true that, in this case, lead would not be as suitable for gamma shielding material, and would have to be replaced by stronger materials such as aircraft structural steel.

In this case, however, there would be no significant gain as far as the weight of the shield is concerned. Calculations show that the weight of a steel shield is not more than 5% greater than that of a lead one, and that a steel shield may be designed as part of the structure of the aircraft, which in the long run would result in a reduction of the weight of an aircraft with steel shields by comparison to that of an aircraft with lead shields.

At present, persistent efforts are being made to find means of reducing the weight of the shielding. The foreign press carries reports to the effect that in the United States and Britain, shielding materials have been discovered permitting the weight of the shielding to be reduced by a factor of 5 - 6 and that a plan for an atomic aircraft with a flying weight of only 42 tons has already been drawn. No confirmation of these reports has been received and it is not possible to vouch for their veracity.

At the same time, there are many interesting and in some cases quite shrewd and bold proposals to reduce the weight of the shielding and to create suitable conditions for passengers and service personnel of an atomic aircraft. One thing, however, is certain: the problem of biological protection has not been solved.

Abroad, many specialists believe that the first aircraft to be built will be an atomic bomber, in view of the fact that it is easier to provide radiation shielding since a crew of only 3 - 5 members will have to be protected. A transport modification of the atomic aircraft will follow some years later. Nevertheless, preliminary calculations of the cost of an atomic passenger aircraft and the cost of its operation were made in other countries as early as 1953 - 1954. As examples for this purpose, a plan was studied for an atomic aircraft with a 15-ton payload, designed to carry 180 passengers at 1600 km/hr for an unlimited distance. The cost of an aircraft with these characteristics was estimated at 9 billion francs, while the cost of the large Comet-3 passenger aircraft was only 700,000,000 francs. However, if the reduction in operating cost, the savings in

cost of chemical fuel, and similar factors are taken into consideration it is felt that a saving of 5 billion francs would be made annually for each atomic aircraft. This permits the hope that atomic aircraft will rapidly amortize their manufacturing cost.

Special Take-Off and Landing Features of Aircraft with Atomic Engines

The difficulties involved in using atomic power plants in aviation also include the fact that while today's heavy aircraft lose almost 50% in weight before landing due to the fuel consumption in flight which improves their landing characteristics, nothing of the kind can be expected of atomic aircraft which means that landing must be made at the same weight as that for take-off. This will, of course, increase the landing speed, the length of the landing run, and in general will complicate landing, making it more difficult and dangerous. The high landing speed of atomic aircraft will compel a lengthening of the runways, construction of stronger landing gear, etc.

However, a careful examination of this problem of the hazards connected with landing an atomic aircraft shows that they are not as insurmountable as might seem. The designers of modern high-speed aircraft were always faced with the task of reducing impermissibly high landing speeds and excessive landing runs. The landing speed and, consequently, the length of the landing run of an atomic aircraft may be reduced by the same means applied or being developed today for modern high-speed aircraft. These include, primarily, an efficient active mechanization of the wing and fuselage for take-off and landing: slots, flaps, and other devices for increasing the lift of the aircraft at low speed. At present, special devices are being developed to control the boundary layer of the air flowing round the wings.

In landing, special pumps are used for removal of the boundary layer by suction from the upper surface of the wing. It would be even better if this air could then be used to "blow away" the eddies forming at the wing at high landing angles

of attack. Moreover, there are interesting proposals to develop special "air flaps" for increasing the coefficient of lift of a wing on take-off and landing. Measures of this type would make it possible to increase the lift of the wing of an atomic aircraft during landing by several times, meaning that the landing could take place at speeds so low as to be safe. The length of the landing run can be reduced to a minimum by using brake parachutes, by reversing the thrust of the engine (i.e., by creating thrust in the opposite direction) and by a number of other measures, such as "braking" devices on the runway.

In view of the problem of landing difficulties, it seems desirable first to plan and build large atomic hydroplanes which will take off and land at sea, where the landing strip is of whatever length required. In the United States, such a plan has been under development since 1955, and at present the first variant of an atomic hydroplane is under construction. The advantages claimed for this variant are the presence of water, which prevents radioactive contamination of the locality during landing and take-off and the absence of restrictions as far as take-off and landing distances are concerned. The first test flights may be performed over the ocean wastes. This also simplifies the problem of shielding.

The landing and take-off characteristics of atomic aircraft assume a completely different aspect if vertical take-off aircraft are considered (Figs.59a, 59b). This type of aircraft has been given particular attention during recent years. An aircraft with vertical take-off and landing combines the highly desirable properties of high flying speed and possibility of basing not only on airfields but also on relatively small natural fields. The difficulties in creating an atomic vertical take-off aircraft are great, since this requires the development of a power plant that will be able to produce a sea-level thrust 30 - 40% greater than the weight of the aircraft. Such thrusts and capacities are within the realm of possibilities, but here a lightweight and advanced shielding is particularly necessary, so as to obtain the necessary ratio of shielding weight to aircraft weight,

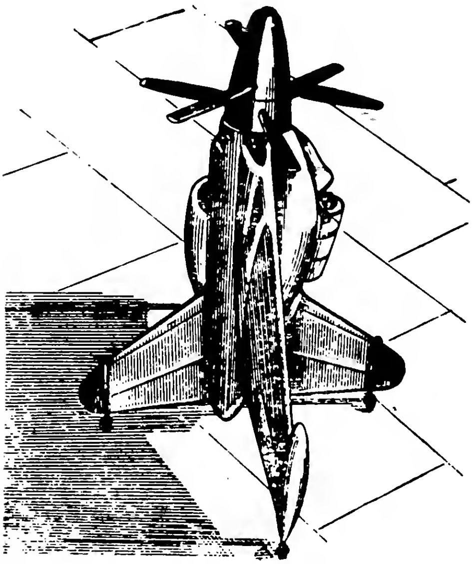

Fig.59a - Vertical Take-Off Aircraft

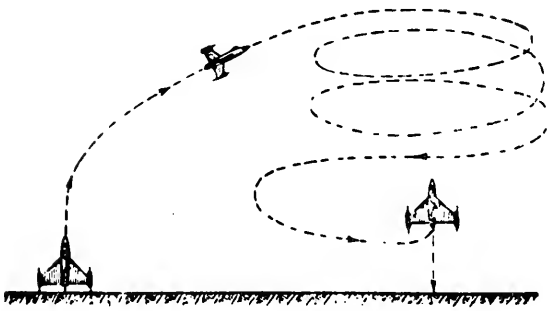

Fig.59b - Schematic Sketch of Vertical Take-Off and Vertical Landing of Aircraft with Turboprop Engine

in view of the enormous reactor power required.

More within reach at present may be the creation of an atomic helicopter of large carrying capacity (Fig.60). In this design, vertical take-off and landing

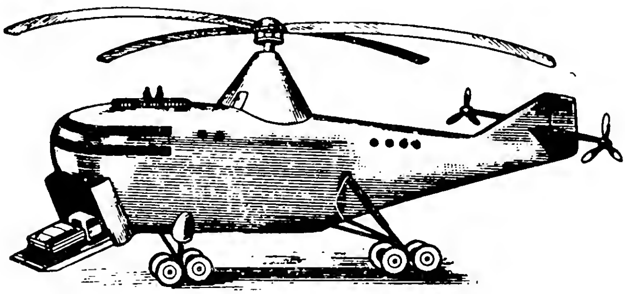

Fig.60 - Probable Aspect of a Heavy Helicopter with an Atomic Power Plant

could be ensured with a reactor of considerably less power than in a regular aircraft with vertical take-off. The rotors of a helicopter, rotating at low speed, develop a sea-level thrust exceeding the weight of the helicopter with engines of a power below that of the rapidly rotating propellers of regular aircraft with vertical take-off. It is true that the extremely large lifting rotor interferes with high speeds in horizontal flight. When the rotating rotor is in the streamline flow of the ambient air around the rotating rotor in horizontal flight, the considerable difference in the speeds of the blade which, at the given moment, is moving against the airflow (forward) and that of the blade moving with the flow (rearward) causes a helicopter to begin losing stability at a speed of about 300 km/hr and creates the risk of nose-over and crash. The speed at which stability is lost is known as the critical speed of a helicopter; at present, it is impossible to exceed this speed.

Despite the comparatively low horizontal flying speeds and the limited critical speeds, helicopters built in the USSR have been widely applied thanks to their advantages on take-off and landing. The ceiling and range of modern helicopters with chemical fuels are small. The development of a helicopter with an atomic power plant will permit a significant increase in range and to extend the area of usefulness of helicopters in general. Heavy atomic helicopters will make it possible to carry freight and passengers over enormous distances, without need to refuel at airfields and, for that matter, without the need for airfields at all.

Even more attractive is the concept of an atomic convertiplane (Fig.61). This is a combined type of aircraft capable of taking off and landing vertically on small areas. In flight, the engines are able to rotate from the vertical to the horizontal position, and the convertiplane is able to develop significantly greater speeds in horizontal flight than the customary type of helicopter. The installation of atomic turboprop engines will make it possible for a convertiplane to fly any desired distance and to land at any point on the surface of the earth. It would be within the power of such an aircraft to carry an expedition from Moscow to the Antarctic or any other distant point on the surface of the earth within a single day, to fly around the world within 24 hours, and rapidly to transport passengers, emergency freight, mail, etc. to any desired distance. Moreover, this will require no intermediate landing fields, bases, or fuel depots, nor will the vast expenditures for the construction of intermediate landing fields be necessary or the cost of delivering hundreds and thousands of tons of chemical fuels to such airfields.

Special Features of Ground Servicing of Atomic Aircraft

The difficulties encountered in designing atomic aircraft are exceedingly great, and some have not been overcome to this day. However, in addition to the difficulties in designing the aircraft themselves, there are difficulties in oper-

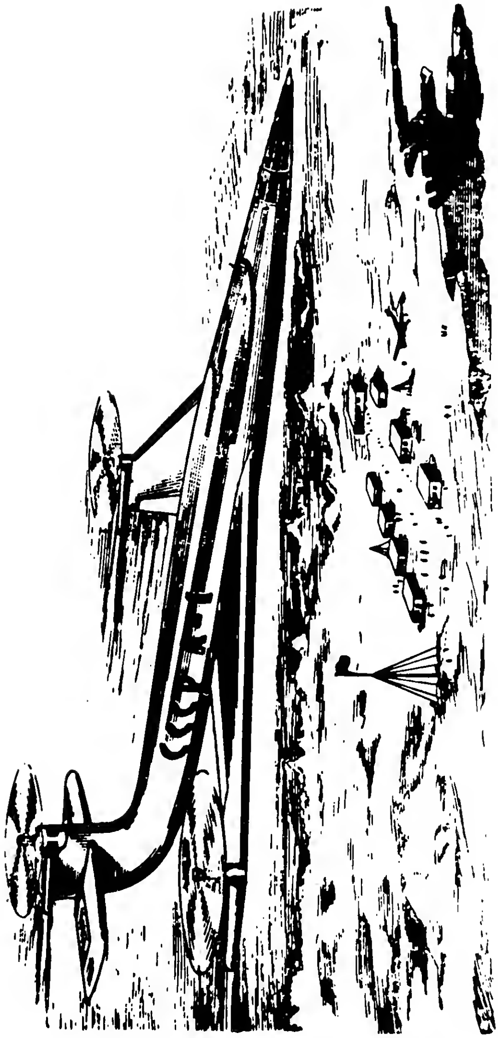

Fig.61 - An Atomic Convertiplane of the Future in the Antarctic

ation and servicing such ships.

The special features of operating atomic aircraft are due primarily to the radiation hazard which complicates the work done in flight, and also inspection, adjustment, and repair work both to the atomic power plant and to the atomic aircraft as a whole. A number of operations will be performable only by means of automatic, remote-controlled equipment which will have to be available at the time at which the first atomic aircraft is built and, as a matter of fact, somewhat earlier.

The organization of flight servicing aboard atomic aircraft will have to be at an absolutely strict and even higher level than the organization of the operation of conventional aircraft.

The servicing of an aircraft in flight will primarily have to provide for constant and precise control of the radiation level aboard the aircraft and at the parking apron on the ground. Each member of the service crew will have to have exact knowledge of his responsibilities both during normal work and in case of emergency. The skill of the engineering and technical personnel of the group will have to be beyond reproach so that each member will be able to make a conscious and accurate evaluation of every step he takes, will know the possible consequences, and will be able to take the necessary precautionary measures in this connection. As far as possible, every step must be reversible. This means that any device, once started, must have been provided in advance with means for stopping it (if necessary, very rapidly).

The above statements prove that an atomic engine and aircraft must be designed with consideration not only of its flying characteristics but also of its major operating characteristics, in order to provide convenience and safety for service in flight and on the ground. Calculations show that, in an atomic aircraft capable of flying at supersonic speeds, "shadow" shielding will provide normal conditions of work only for the crew compartment; outside this zone, the safe distance in the case of a reactor operating at full power will be not less than 1000 - 1500 m or

100 - 200 m after the reactor has been turned off. Consequently, to provide for safety of ground servicing, the atomic power plant must be so designed that the re-

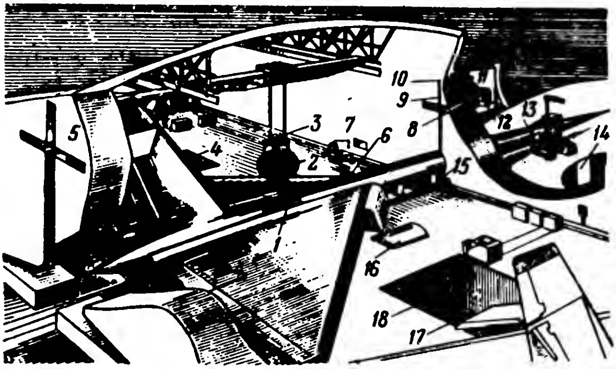

Fig.62 - One of the Proposed Variants of an Atomic Aircraft and Inside Design of a Service Hangar

1) Location of reactor; 2) Reactor; 3) Television camera; 4) Well; 5) Shielding walls; 6) Bomb bays; 7) Radiation counters; 8) Lead glass window; 9) Television antenna; 10) Periscope; 11) Control room; 12) Television control panel; 13) Cockpit shielding; 14) Tunnel for crew; 15) Rail trolley for moving aircraft; 16) Reactor cover; 17) Immersed reactor; 18) Well into which reactor is immersed

actor can be readily removed from the aircraft after landing. Moreover, when using an atomic engine with a liquid heat-transfer agent, special measures must be provided for dumping this agent after the flight, since it will also be radioactive. When using an atomic turbojet engine with direct heating of the air in the reactor, of the type illustrated in Fig.33, the entire engine will be radioactive, which means that the entire engine nacelle will have to be readily dismountable.

These specific features of design and operation of aircraft with atomic power plants dictate the necessity for special equipment at landing areas, airfields, and hangars for atomic aircraft, particularly for the first experimental models. The airfield must have special storage provisions and underground laboratories for reactors, for the heat-transfer agents, and other radioactive materials and assemblies. A foreign journal carried a drawing (Fig.62) showing a proposed design variant for an atomic aircraft hangar.

In addition to developing special hangars it is also necessary to provide complete mechanization and automation of all work involving reactors, radioactive heat-transfer agents, and in some cases the engine as a whole. Experience with stationary reactors has shown that modern technology, in addition to the simplest types of manipulation, has also made possible complex, laborious, and very precise operations, by means of sensitive instruments and so-called "mechanical hands". For modern science and engineering, the development of ground equipment for transport of highly active reactors, for installation and removal of reactors by remote control, for connecting and filling the cooling systems with liquid or gaseous heat-transfer agents presents no great difficulty.

In addition to the mechanization means, airfields for atomic aircraft with "shadow" shielding must be equipped with shelters and comfortable air terminals with underground installations for passengers and service personnel. In the first atomic aircraft, it may well be that such special devices will also be required for entering the aircraft and particularly for leaving it after landing, before the reactor has been removed.

The need for much of this ground equipment will naturally be eliminated as soon as a reliable integral radiation shielding for aircraft reactors will have been developed. When this is the case, ground servicing will become simpler and safe; however, for the time being this is a matter for the future (Fig.63).

The preparations for starting and the actual startup of an atomic power plant

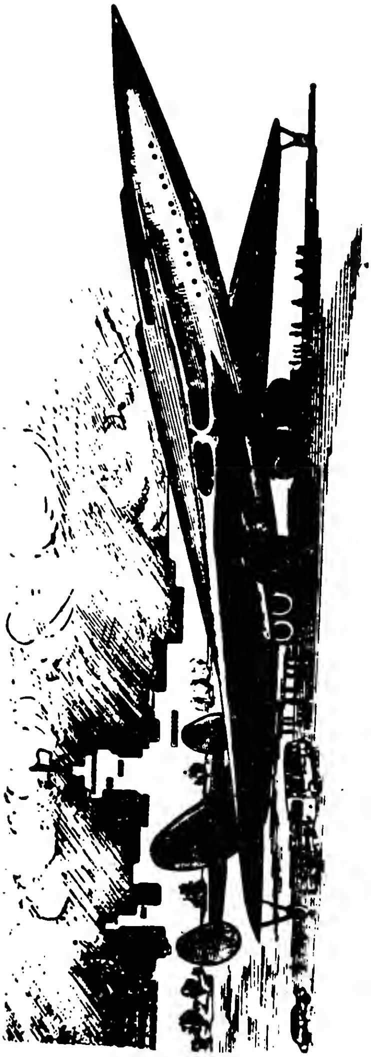

Fig.63 - Variant of Atomic Aircraft with Effective Omnilateral Radiation Protection

on an aircraft will involve certain difficulties with respect to preliminary heating of the heat-transfer agent and initiation of its circulation in the system, for agents which are in a solid or viscous state at ambient temperatures. From this point of view, and in order to reduce the radiation hazard on take-off and landing, certain designers consider it desirable to use compound power plants with both nuclear and chemical fuel. The chemical fuel can be used for starting, heating the engine, and for take-off and climb. In flight, when the heat-transfer agents have been preheated and circulation is in progress, the transition to nuclear fuel would take place, i.e., the reactor would be turned on. However as already stated, the use of combination engines of this type involves considerable difficulties and leads to an increase in the design weight, at the same time requiring a large reserve of chemical fuel aboard the aircraft which is of course unprofitable.

The problems of operating atomic aircraft include another unavoidable phenomenon. For some time after being

turned off, the reactor will continue to emit fairly large quantities of heat due to the radioactive decay of fissioned particles. During this period, circulation of the heat-transfer agent must be maintained by means of special installations at the airfield, or the reactor must be immersed in a tank containing a coolant. Therefore it is advisable, in selecting the landing means, to consider the necessity of removal of the "residual" heat. During the landing approach, it would be necessary to reduce the power of the reactor to a minimum and to turn it off completely after landing. This will permit a rapid cooling of the reactor, even with comparatively small airfield installations.

The special features inherent in the operation of the first atomic aircraft again emphasize the complexities and difficulties involved in the development and the initial use of such aircraft. It is only thanks to the high level of development of modern science and engineering that it will be possible to overcome all these difficulties. An especially important role in this connection will be played by such branches of science and engineering as automation, telemechanics, television, etc. As time passes, the complex and expensive equipment will be perfected, simplified, better thought out, made cheaper, and simpler in shape. The air fleet will receive powerful atomic aircraft which will be greatly superior to the aircraft of today in qualities and properties.

CHAPTER V

ATOMIC ENERGY AND INTERPLANETARY FLIGHT

The use of atomic energy opens broad perspectives for the solution of the exceedingly difficult problems involved in performing cosmic flights and mastering the universe.

What are the objects of cosmic flight? Is there any sense in working to achieve these objects?

These questions may be answered first by mentioning the advantages to science as a result of mastering interplanetary space. Even the launching of the first rockets - first artificial earth satellites - will make possible the creation of extraterrestrial laboratories for physical, chemical, and biological research under conditions of "weightlessness", low temperatures, and high electric discharges. It will be possible to create extraterrestrial weather stations, rebroadcasting stations for short-wave radio and television transmission, astronomical obeervatories with visibility undistorted by the atmosphere. All this will have a tremendous scientific and practical value. The development of artificial earth satellites and, later, of space ships for flights to other planets will be a new and important step along the road of knowledge of and conquest of nature by man.

As early as the beginning of the Twentieth Century, scientists were able to determine mathematically the conditions required for the performance of interplanetary flights. The studies of the late Russian scientist, K.E.Tsiolkovskiy are of fundamental importance in this connection. He laid the foundation for the science

of interplanetary communications, called astronautics. K.E.Tsiolkovskiy was the first to formulate clearly the concept that the only flying machine suitable for cosmic flight is the rocket, and the only motor able to operate in airless space is the rocket engine and, in particular, the liquid-fuel rocket (LFR) which was first proposed by Tsiolkovskiy. Tsiolkovskiy understood clearly how much labor, preliminary investigations and experiment would be required on the part of engineers and designers before an aerial interplanetary vehicle could be developed that would be able to overcome the gravitational field of the earth and fly into cosmic space.

What are the major engineering difficulties in cosmic flight and what are the practical possibilities existing today for the development of an interplanetary rocket?

When the horizontal flying speed is low, a rocket will (as is known) ultimately return to earth. In order for the rocket not to fall but to continue moving at the same altitude around the earth, thus changing to an artificial satellite, it must attain a given horizontal flying speed, which is known as orbital or first cosmic speed. This speed is not constant. Near the surface of the earth, it is 7900 m/sec and decreases with increasing altitude. At an altitude of 200 km, the orbital velocity of a satellite rocket must be approximately 7800 m/sec (28,000 km/hr), while at an altitude of 800 km this speed will be 7400 m/sec. A sputnik, 35,800 km distant from the earth and moving in the plane of the equator from West to East at a velocity of about 3000 m/sec, will be termed "stationary" since it will make one revolution every twenty-four hours together with the earth.

If the force of terrestrial gravity did not exist, then every body given a horizontal impetus would move by inertia in a straight line and at uniform speed and would travel into cosmic space at a tangent to a circular path, whose center would be at the center of the earth. But the effect of gravity compels a body to deviate from this path relative to the earth. At low velocities, a body falls back toward the earth. At orbital velocity, the body is able to fall only as far as is

necessary for it to attain an orbital path. The force of gravity constantly changes the direction of motion of a body, holding it in that path.

Today, after the development by the USSR of the world's first artificial satellite, it will be possible to proceed to the next stage in mastering cosmic space - the dispatch of a controlled rocket to the moon. In order for the rocket to overcome the force of terrestrial magnetism and fly to the moon, it has to attain the second cosmic speed of 11,200 m/sec (more than 40,000 km/hr).

What means are required to reach such high flying speeds?

In order to attain cosmic speeds, an engine which, while small in size and light in weight, will develop a colossal power in airless space will be required. Today, only the rocket engine can meet this requirement. Today, any planetary vehicle or Sputnik is designed as a rocket equipped with a liquid-fuel engine.

Figure 64 gives the design and operating principle of a modern rocket, equipped with a liquid-fuel engine. The sketch shows the principal parts and assembly of the rocket: control and payload section (A), oxidizer tanks (O), fuel tanks (G), turbopump assembly (TPA) for delivery of fuel components to the engine chamber, stabilizer (C), gas control vanes (P), and finally the engine (D) which latter illustrated on a larger scale at the right side of the drawing. The combustion chamber (1) and the jet nozzle (2) serve to convert the chemical energy of the fuel into thermal energy and subsequently into the kinetic energy of the escaping stream of hot gases. The fuel and oxidizer are injected through nozzles into the combustion chamber by the turbopump assembly at a pressure of 5 - 6 atm in the chamber. The oxidizer or the fuel (most often the fuel), prior to injection into the combustion chamber, is circulated through the tube (3) in the space outside the engine jacket to cool the walls of the jet nozzle and the combustion chamber.

The major requirement to be met by a rocket engine is minimum specific fuel consumption or, what amounts to the same thing, high specific thrust. The specific thrust depends on the exhaust velocity from the jet nozzle and, in modern liquid-

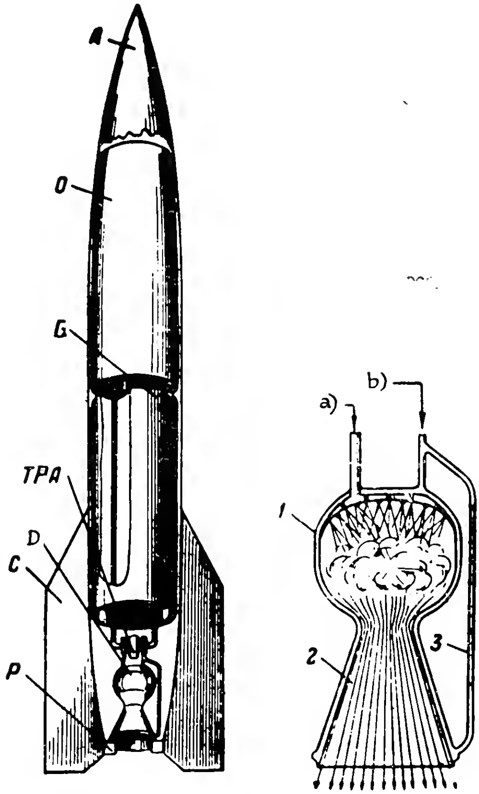

Fig.64 - Design and Principles of Liquid-Fuel Rockets

A - Control and payload compartment of the rocket; O - Oxidizer tank; G - Fuel tank; TPA - Turbopump assembly; D - Engine; C - Stabilizer; P - Gas control vanes; 1 - Combustion chamber; 2 - Jet nozzle; 3 - Tube for delivering fuel to cooling system

a) Fuel; b) Oxidizer

fuel engines, is 200 - 300 kg-sec/kg (200 - 300 kg of thrust per combustion of one kilogram of fuel mixture per second). The exhaust velocity, in turn, depends on the temperature and pressure of the gases in the combustion chamber and also on the molecular weight of the combustion products. In modern liquid-fuel engines, the temperature in the chamber reaches 2500 - 3000°C, and the exhaust velocity from the jet nozzle ranges from 2000 to 3300 m/sec. When using fuel components of optimum efficiency, e.g., a mixture of hydrogen and fluorine, the exhaust velocity of the gases may be brought to 4000 m/sec.

Speeds and Altitudes Attained

Rocket engineering, in the past 10 - 20 years, has undergone considerable development. After World War II, rockets equipped with liquid-fuel engines have come into wide use, both for military purposes and for scientific studies of the upper layers of the atmosphere. There is constant improvement at the engineering end with respect to velocity, altitude, and range of rocket flight. Single-stage military and meteorological rockets today rise to altitudes up to 300 km and develop a maximum speed of over 6000 km/hr, corresponding to 5 - 6 times the speed of sound. The range of single-stage rockets exceeds 400 km.

It is no longer possible to expect further significant gain in speed and range merely by increasing the dimensions of a single-stage rocket. Therefore the majority of powerful new rockets is designed as multistage rockets (Fig.65). A step rocket is able to rise to more than 1000 km and fly thousands of kilometers. Such rockets have been given the name of strategic intercontinental ballistic missiles and are now beginning to gain major military significance. In a number of countries, an extensive program for the development of intercontinental rockets has been under way for several years. Abroad, the development of a three-stage rocket is under way. This rocket is to develop a speed of 15 times the speed of sound (18,000 km/hr). The final stage of this rocket is to rise to an altitude of 915 km

and to have a horizontal range of about 8000 km. The development of a multistage intercontinental rocket with a range in excess of 8000 km and traveling at 20 times

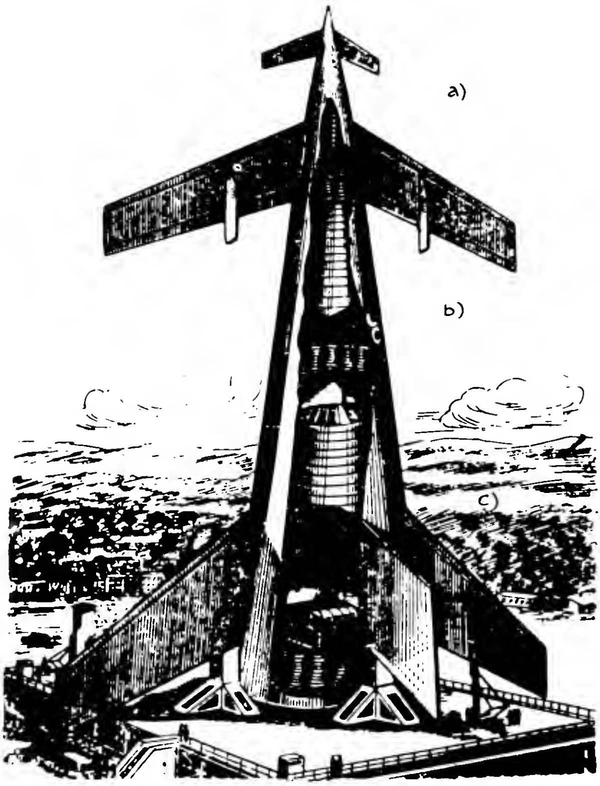

Fig.65 - One Design of a Multistage Rocket

a) Third stage; b) Second stage; c) First stage

the speed of sound is projected as a subsequent step. The highest point in the trajectory of the rocket is 1280 km, and the terminal velocity at the end of the

powered portion of the flight will be 6700 m/sec (24,100 km/hr).

Our scientists and inventors have always given much attention to the development and perfection of various types of rocket armament. During World War II no army on earth had rocket armament as effective as those of the glorious Guard Mortar men of the Soviet Army. At present, the Soviet Armed Forces are equipped with every variety of the most modern jet and rocket equipment, including rockets of long and superlong range (intercontinental, multistage ballistic rockets).

In reviewing the truly grandiose success of rocket engineering in our day, we would like to draw the attention of the reader to the fact that the development of rocket engineering paves the way for further rapid progress in special branches of science and engineering, industry, and transport. The development of rocket engineering has served as a helpful preparatory stage for reaching cosmic velocities, for the further development in the very next few years of artificial earth satellites and, in the not-too-distant future, of interplanetary flights. The development, testing, and perfection of giant rockets, equipped witn powerful liquid-fuel engines, has already considerably reduced the distance between the theoretical work of Tsiolkovskiy and the practical realization of the first cosmic trip.

Two Means of Attaining Cosmic Velocities

From K.E.Tsiolkovskiy's equation for the terminal velocity of the powered section of a rocket flight, $V = 2.3 \cdot W \cdot \log\left(\frac{G_{in}}{G_{fin}}\right)$. Obviously, the velocity V, reached by a rocket when all its fuel has been consumed, depends on the exhaust velocity W of the gases from the jet and on the ratio of initial to terminal weight of the rocket $\frac{G_{in}}{G_{fin}}$. Tsiolkovskiy's equation may be understood on the basis of the simplest physical reasoning. Other conditions being equal, the thrust and economy of a rocket engine is determined by the exhaust velocity of the gases. The higher the exhaust velocity, the higher will be the thrust created by each kilogram of gas derived from the fuel mixture and the more efficiently the fuel stored in a

rocket be utilized. At present, very high exhaust velocities have been attained; loud whistling and roar accompany the blinding flash of ignited gases that may be described not so much as a discharge but as an eruptive ejection from the nozzle of liquid-fuel engines of medium thrust. This is even more striking for engines of high thrust. It is absolutely unsafe for an unprotected person to be near the launching pad during the take-off of a large high-altitude rocket (Fig.66).

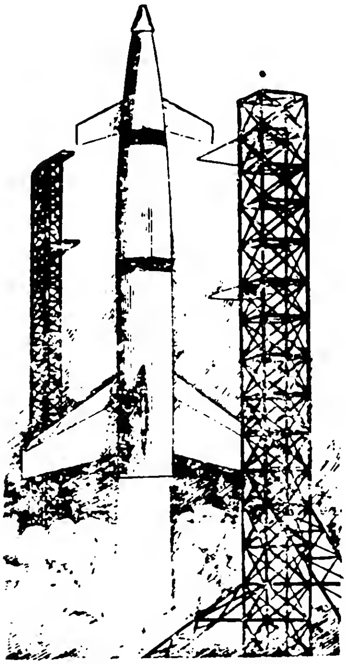

Fig.66 - Take-Off of Powerful High-Altitude Rocket

However, the exhaust velocities reached at present are inadequate for interplanetary flights.

Reaching exhaust velocities in excess of 4000 m/sec by chemical fuels is exceedingly difficult. Further increase in the speed of rocket flight has to proceed entirely by improvement in design, i.e., by increasing the ratio of the fuel weight to the weight of the empty rocket. It follows from Tsiolkovskiy's formula that even at exhaust velocities of 4000 m/sec, it would be necessary, in order to reach the second cosmic speed of 11,200 m/sec, to produce a rocket whose airframe together with engine, tank, and equipment would weigh only $\frac{1}{16}$ of the initial fuel capacity. In addition, the above Tsiolkovskiy equation was derived without consideration of atmospheric resistance and the effect of terrestrial magnetism. If these factors are taken into consideration and if the exhaust veloci-

ties actually attained are entered into the calculation, we find that for each kilogram of airframe, equipment, and payload a rocket must carry at least 25 - 30 kg of fuel. The development of a rocket with such load data today encounters insurmountable engineering difficulties; for this reason, systems of step rockets or "rocket trains", as K.E.Tsiolkovskiy called them in his day, must be used.

Much has already been accomplished by engineers and designers to develop advanced rocket designs. By using the lightest and strongest structural materials and by developing rational layouts, it has become possible to have the modern rocket carry a fuel supply 5 - 6 times as great as its structural weight. Further improvement in rockets with respect to weight will encounter ever greater difficulties, and it will again be necessary to return to the problem of increasing the exhaust velocity, of increasing the energy supply per unit weight, and particularly of increasing the unit volume of rocket fuel.

Nuclear or Chemical Fuel?

The concept of applying atomic energy for attaining cosmic speeds and performing interplanetary flights was originated a long time ago. As early as 1926, K.E.Tsiolkovskiy directed attention to making use of the enormous sources of energy within radioactive elements, and posed the question of using radium as fuel for a rocket engine.

At present, thanks to the progress made in nuclear physics, to the development of a rapidly progressing science of atomic power, and to the creation of an atomic industry, we have come close to the solution of the problem of making use of atomic energy in rocket engineering.

However, even today, many scientists believe that the first interplanetary trip by man will not be made with nuclear but with conventional chemical fuel. Another, and in fact, much larger group of contemporaries hold that interplanetary flights are impossible with conventional chemical fuel and that a more powerful

source of energy such as nuclear energy would have to be used, or else that new discoveries or methods for circumventing this problem will have to appear. One such method was proposed in 1956 by Professor G.A.Chebotarev who showed by calculation the possibility that a rocket ship could fly around the moon and return to earth without using fuel. All that is needed is for the rocket to attain an initial velocity of 11.2 km/sec to overcome gravity. All the rest of the flight will be made by ingenious use of the interlocking gravitational fields of the moon, earth, and sun.

Let us attempt, at least, a qualitative description of the problem of using nuclear fuel for interplanetary rocket engines.

Advantages of an Atomic Rocket Engine

The first advantage of nuclear fuel for rockets usually suggested is the colossal energy or thermal capacity it provided. However, in order for a rocket to move forward at high speed, what is needed is not only energy but also a mass to be expelled backward (a liquid or gas) which, escaping from the engine at enormous velocity, will create reactive thrust. The fact that, in the chamber of an atomic liquid-fuel rocket, heat for heating the gases is not produced by the chemical reaction of combustion but by nuclear reaction, does not mean at all that we have provided thrust for the rocket. The energy is available and enough of it can be generated by fission of nuclear fuel, but application of this energy in the form of heat is of little use since there is not enough mass to be ejected for the creation of thrust. Consequently, a rocket with an atomic liquid-fuel engine, like an ordinary rocket, must carry enormous quantities of its working medium aboard, together with an inertial mass which is able to convert the thermal energy of the nuclear reactor into kinetic energy of a continuous gas jet.

The second advantage of nuclear fuel results from the first and consists in the fact that this fuel may be used to attain, theoretically, any temperature no

matter how high in the chamber of the rocket engine. It is known that temperature is one of the main decisive factors in obtaining high exhaust velocities and specific thrusts in a rocket engine. Here, however, an obstacle is encountered. At the temperatures in conventional liquid-fuel engines with chemical fuels (up to 3000°C and more), considerable difficulties are already encountered in the selection of structural materials and the provision of dependable cooling for the combustion-chamber walls and the jet nozzle of an engine. At the slightest difficulties in the cooling system, the walls of a high-temperature liquid-fuel engine will fuse and burn as rapidly as lead foil over a gas burner.

Nuclear reactions make it theoretically possible to reach temperatures of 5000 - 10,000°C and more in the chamber of a liquid-fuel engine. This permits enormous exhaust velocities, several times greater than those of modern liquid-fuel rockets. However, this second advantage of nuclear fuel cannot be utilized until structural materials able to withstand such high temperatures are available. Moreover, nuclear reactors for a rocket engine, using the most refractory of the materials known today, even in theory, will not permit working gas temperatures above those reached by ordinary liquid-fuel rockets with chemical fuels.

Why is this the case?

In order to understand this point, it is sufficient to recall our discussion of the fact that, for reaching the same temperature in the working gases, the temperature of the structural materials of an atomic engine must not only be higher than the temperature of the structural materials of a conventional engine but must be higher than the temperature of the working gas in the engine.

The literature contains a number of proposals on creating high-temperature reactors for rocket engines. An example of such a reactor is that of the atomic liquid-fuel rocket shown in schematic outline in Fig.16. The graphite reactor core has a porous structure and is provided with longitudinal conical channels. Fused uranium (the reactor is designed to operate at 3150°C) is contained in fine honey-

combs within the graphite, which still retain a certain strength at this temperature. Through the ducts in this porous mass hydrogen is propelled by pumps, and this hydrogen, heated in the reactor, should, in the opinion of the inventor of this design, escape from the jet nozzle at a velocity of 7300 m/sec.

Unfortunately, there are many reasons for doubting the possibility of developing such a reactor, particularly its mechanical strength and dependability under the effect of variable temperatures and powerful streams of hydrogen.

The third advantage of nuclear fuel for a rocket engine lies in the fact that an atomic liquid-fuel rocket does not require, as its working medium, two specially selected components (fuel and oxidizer) as in ordinary liquid-fuel rockets, but only one (the inertial mass). Ordinary distilled water, which not only can be converted in the reactor into superheated steam but can also be decomposed into its constituent elements (oxygen and hydrogen) which will escape from the engine nozzle and create reactive thrust, is one possibility as an inertial mass. Water actually is the cheapest inertial mass for an atomic rocket, but it is not the best in terms of maximum exhaust velocity and high specific thrust. The selection of the inertial mass must be based on calculations for obtaining maximum exhaust velocity of the gas stream. This desirable property is exhibited by chemical elements of low molecular weight and therefore, maximum exhaust velocity can be obtained with atomic hydrogen and, as the next best, with ordinary hydrogen. A stream of hydrogen, heated to a temperature of 4000 - 6000°C, should give an exhaust velocity of the order of 8000 - 10,000 m/sec.

A major shortcoming of hydrogen is its low specific gravity. Even in the liquid state, one liter of hydrogen weighs only seventy grams, i.e., less than $\frac{1}{14}$ of one liter of water. This drawback of hydrogen, when considered in the light of its positive properties, has been the cause of a scientific debate conducted for many years among distinguished scientists and specialists, in the field of rocket engineering. Thus, refuting the contentions of Professor N.G.Chernyshev (Bibl.25),

V.P.Glushko, Member of the Academy, has repeatedly asserted that hydrogen is a fuel without a future as far as rockets are concerned, because of its low density and because of the difficulty in storing enough of it aboard a rocket. A rocket, using hydrogen as fuel, would ordinarily have enormous dimensions and thus high drag as it moves through the dense layers of the atmosphere.

This shortcoming of hydrogen is particularly disturbing to scientists concerned with the problems of astronautics. Thus, today, the way out of the situation is to use chemical compounds of hydrogen of high specific gravity, in the liquid state, which yield high quantities of atomic hydrogen when decomposed at high temperatures. Substances of this kind known today include ammonia (NH_3) and ordinary water (H_2O), which may be regarded as a possible inertial mass for atomic liquid-fuel rockets, along with hydrogen.

Projected Atomic Space Rockets

Confirmation of the above-described advantages and disadvantages of nuclear fuels is found in virtually all designs of atomic space rockets now suggested.

The maximum possible theoretically attainable exhaust velocity is equal to the speed of light (300,000 km/sec). On this basis, it has been suggested that the actually obtained exhaust velocities be compared with the velocity of light and that rockets be categorized accordingly as gas, atomic, and photon rockets.

Today only gas rockets are in existence (rockets using gas as the ejected mass). In turn, these are subdivided into solid-fuel (powder) rockets, liquid-fuel, and thermo-atomic rockets. Powder and liquid rockets have already produced exhaust velocities somewhat greater than 0.00001% of the velocity of light. Thermo-atomic rockets, i.e., rockets using the heat of a nuclear reactor, are today in the design stage and will, in the course of time, be able to produce exhaust velocities 0.0003% - 0.0001% of the velocity of light. Pure atomic rockets, which will be able to create thrust directly by ejecting the nuclear reaction products, and photon

rockets whose thrust is created by the irradiation of powerful light beams, are as yet purely hypothetical.

At present, of the various types of atomic rockets, only thermal rockets seem realizable in practice. These rockets use the thermal energy of a nuclear reactor to create high temperatures in the combustion chamber of liquid-fuel rockets.

Ten years ago, the first sketch of a rocket satellite, using an atomic liquid-fuel rocket, was published in the foreign press. The author of this project proposed that an atomic liquid-fuel engine be mounted in a single-stage rocket with the object of reaching an orbital velocity of 8270 m/sec. In the combustion chamber of the engine, it was proposed to house a radium and graphite reactor weighing 32 tons and using thermal neutrons. On the basis of the calculations, 3160 kg of hydrogen would have to pass through this reactor per second. (The fuel flow through the well-known German V-2 rocket was only 125 kg/sec.) It is believed that the thrust, when hydrogen is heated in a reactor to 3150°C and the exhaust velocity is 7300 m/sec, will be as high as 2350 tons, which is approximately 100 times as high as the thrust of the V-2 (25 - 26 tons). In order for a rocket with this type of atomic liquid-fuel engine to reach a speed of 8270 m/sec, the engine has to consume 1130 tons of liquid hydrogen in the 358 sec of operation during powered flight. The total take-off weight of the rocket would be 1410 tons.

Obviously, the scale of this project is more in the category of a science-fiction novel than realizable from an engineering viewpoint. Therefore, the next variant of the calculation was one that constituted a closer approximation to reality: weight of the reactor 14.8 tons, hydrogen consumption 1520 kg/sec, engine thrust 1140 tons at a take-off weight of 685 tons for the rocket as a whole.

The major difficulties encountered in the use of a reactor in a liquid-fuel rocket chamber are those of providing high temperatures and reliable conditions of heat liberation. We know that uranium fuses at a temperature of 1130°C, while graphite vaporizes at a temperature of about 3700°C. Therefore, certain authors

propose another means of applying nuclear energy in a rocket engine: injecting the nuclear fuel into the liquid-fuel engine in the form of a solution or suspension.

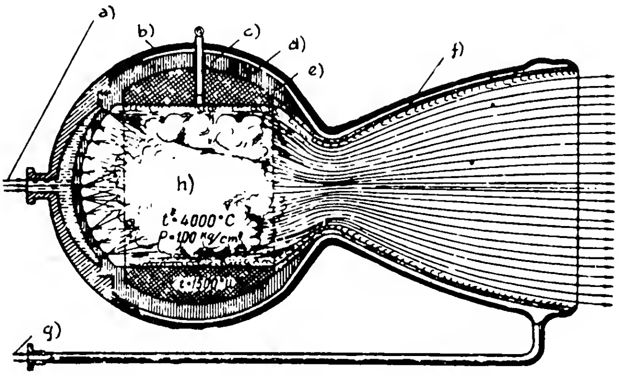

Fig.67 - Schematic Sketch of an Atomic Liquid-Fuel Rocket with "Subcritical" Reactor

a) Supply of nuclear fuel in suspension; b) Shell; c) Control rod; d) Reactor; e) Porous reflector; f) Porous interior wall; g) Supply of liquid hydrogen or water; h) Zone of high-temperature nuclear reaction

Application of nuclear fuel in this manner will provide for adequate temperatures and good conditions for heat liberation in the eddy flow of gases. However, the trouble is that the dimensions of the chamber of such an engine would have to be excessively large. The critical state of the homogeneous gas mixture in which the nuclear reaction would have to occur, is determined by the product of the pressure in the chamber and its radius. According to certain calculations, a mixture of hydrogen and atomized nuclear fuel at a temperature of 5000°C and at 100 atm pressure would require a chamber of at least 240 m diameter. To produce a chamber of this kind is something that obviously no one has undertaken, but the logical

thought arises of combining the first and second principles to make use of the advantages and diminish the shortcomings of both.

The device in the chamber of this engine (Fig.67) is not a solid but a porous annular reactor, made of refractory uranium carbide and graphite and enclosed in a porous graphite reflector. Before the engine is started, the reactor is subcritical and does not operate. On manipulating the control rods, the activity of the reactor increases and, after hydrogen and a small amount of uranium powder have been injected into the chamber, the system becomes critical and begins to generate heat which heats the hydrogen in the high-temperature flow zone of the chamber to 3500 - 4000°C. In this case, the temperature of the reflector and even of the reactor, where significant quantities of heat are also liberated, will not be above 1500 - 1600°C, due to the stream of pure liquid hydrogen which dissipates heat from the structural material of the reactor into the high-temperature zone. The walls of the jet nozzle are of a heat-resistant porous material and therefore etart sweating, as it were, when the engine is in operation. Hydrogen, seeping through the pores, forms a dense film of gas which continually being washed away and just as continually renewed, protects the walls of the jet from the effects of the incandescent flow of gas.

If the average temperature to which hydrogen is heated in the chamber of such an engine is assumed as 3700°C, an exhaust velocity of 8100 m/sec would result. At a consumption of liquid hydrogen of 30 kg/sec (i.e., only $\frac{1}{4}$ as large as in the V-2), a thrust of 25 tons is attainable.

Unfortunately, this variant of the atomic liquid-fuel rocket also has its disadvantages. To begin with, the probability of fission of the nuclei of injected fuel is negligible during the period of time an individual nucleus is in the area of the annular reactor. In all probability, the nucleus of the injected fuel will travel through the chamber of the engine intact and undamaged, without being fissioned. Obtaining any significant number of nuclear fissions would require a

neutron flux of a density impossible to realize in the reactor serving as the neutron source and simultaneously containing the fuel nucleus.

Selection of a Program for Attaining Cosmic Speeds

At the beginning of its flight, a rocket must pass through the dense layers of the atmosphere. Atmospheric air creates significant resistance, and the bulk of the

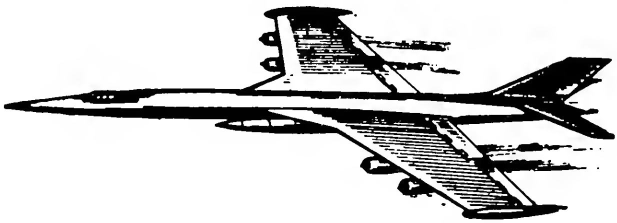

Fig.68 - Atomic Launching Aircraft for Artificial Earth Satellites

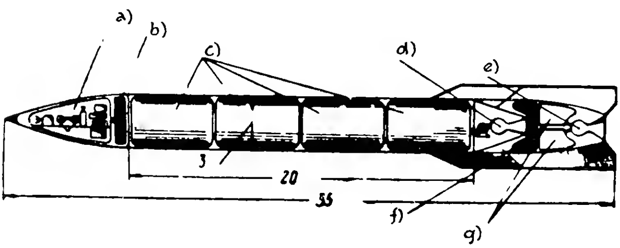

Fig.69 - Schematic Sketch of Two-Stage Rocket for Launching an Artificial Earth Satellite

a) Instrument compartment of satellite; b) Parachute for instrument compartment; c) Liquid-hydrogen tanks; d) Atomic liquid-fuel rocket for second stage; e) Conventional liquid-fuel rocket for first stage; f) Parachute for first stage; g) Tanks for chemical fuel

fuel will have to be used to overcome this resistance. In developing high velocities, even in the comparatively dense layers of the atmosphere, a rocket may be subject to excessive heating due to friction with the air, which is also an undesirable factor.

This raises the question of using, during the first segment of the flight of a cosmic rocket, atmospheric air as the working medium for the atomic engines. It is in this segment, during the first stage of ascent and acceleration of the cosmic rocket, that the advantages of nuclear fuel, with its high energy content, must be utilized to the fullest.

By way of example, we may suggest the following schedule for releasing a whole series of experimental earth satellites: An atomic carrier or launching aircraft (Fig.68) with a payload of 20 - 30 tons would be built. There can be no doubt as to the feasibility of constructing such an aircraft. Aircraft designers agree that the design and development of aircraft with up to 100 tons payload and more represents a problem entirely soluble from the engineering point of view, even today.

The carrier aircraft carries a two-stage rocket (Fig.69) weighing 20 tons to an altitude of 20 km and accelerates it to 600 m/sec in the direction of the earth's rotation from West to East. The density and resistance of the air at 20 km is about $\frac{1}{14}$ that at the earth's surface, so that the danger of excessive heating of the rocket during further acceleration is significantly reduced.

When the carrier aircraft reaches the Sputnik launching area, the operator connects the first stage of the rocket engine. In order to protect the crew of the launching aircraft from the radiations of the atomic liquid-fuel engine, an ordinary liquid-fuel engine, using liquid oxygen and hydrogen, is used for the first stage of the rocket. The characteristics of the rocket, as projected, are entirely attainable at the present time: 35 tons thrust, fuel consumption 104 kg/sec, exhaust velocity 3300 m/sec. After consuming 4500 kg fuel in 43 - 44 sec, the first stage accelerates the rocket to a velocity of 900 m/sec, is separated at an alti-

tude of 34 km, decelerated, and returned by a cargo chute. On separation of the first stage, the main Sputnik engine goes into operation - an atomic liquid-fuel rocket of the type illustrated in Fig.67. With an engine thrust of 28 tons, the rocket will, in 280 sec of final acceleration, reach an orbital velocity of 7840 m/sec at an altitude of 294 km.

The characteristics of the selected two-stage rocket are shown in Table 3, and its approximate dimensions in Fig.69.

Table 3

Rocket Characteristics	Unit	First Stage	Second Stage
Initial weight	Tons	20	14
Weight of fuel	Tons	4.5	9.5
Fuel consumption	kg/sec	104	34
Time of operation	Sec	43	180
Engine thrust	Tons	35	28
Speed at combustion cutoff	m/sec	900	7840
Altitude	km	34	294

The calculations and drawing reveal clearly an undesirable feature of the hydrogen rocket. The volume occupied by 9.5 tons of liquid hydrogen is 135 m^3 which means that the rocket has to be extremely large, because of the hydrogen tanks. If it would be possible in some way to increase the density of the hydrogen, let us say by 14 times, i.e., to bring it to the density of water, the volume of the inertial mass would be less than 10 m^3, and the rocket would be compact with good aerodynamic qualities.

This program for launching satellite rockets has a number of advantages. The launching aircraft, as the first stage of the rocket, may be used repeatedly. The hull and tanks of the second stage do not have to be jettisoned, which will give

the Sputnik greater dimensions and reflectivity, making it easier to observe from the earth. When, as result of the small amount of friction in the highly rarefied upper layers of the atmosphere, the satellite gradually starts losing speed and altitude, the hull and tanks of the second stage can be automatically converted into a kind of air brake for decelerating the instrument compartment before the main parachute opens to save the equipment and instruments. The experience in the operation of such satellites and the experimental data obtained will later make it possible to proceed with confidence to explorations of higher levels of cosmic space.

The more nearly we approach practical steps in the field of astronautics, the more frequently the question arises as to the cost of a satellite rocket, its equipment, launching platforms, and other auxiliary installations. In October 1957 the world's first artificial earth satellite was launched in the USSR. The launching of the first artificial satellite in the United States is planned for 1958. Considerably greater difficulties will be encountered in the development of the first cosmic ship carrying a crew, but this problem also will be solved in the not too distant future.

In view of the facilities that the Party and State have created for fruitful work by our scientists, Soviet science today occupies the leading position in a number of fields. Our scientists are beginning to penetrate the secrets of controllable thermonuclear reactions.

When these reactions are mastered, they will produce several times more energy than the fission reaction. As soon as it is possible to create a controlled thermonuclear reaction within the chamber of a rocket engine, we will have arrived at what is known as a photon rocket, where the thrust will be produced by powerful light irradiation.

Problems of photon rockets have been treated for several years at a small institute of rocket-engine physics, headed by Dr.E.Saenger in the German Federal Republic. It is held, in this institute, that photon rockets will be the final stage

in the development of engines both for aircraft and for interplanetary and cosmic travel. Photon rockets will be able to fly at speeds approximating the velocity of light. Sources of energy for photon rockets can be discovered even today, but the question arises as to what can be done as to the materials to be used for the walls of photon engines, and where to find materials able to withstand such enormous temperatures and pressures.

It can hardly be expected that anyone bothers with these problems today. Apparently, materials of this kind will have to be synthesized. In addition, it will be necessary to develop completely new and efficient methods of cooling and protecting the structural materials from excessively high temperatures.

Many questions having to do with problems of the practical realization of interplanetary flights have not yet been investigated, and their solution will take time, tremendous efforts, and enormous expenditures of materials. However, the rapid development of modern aviation in rocket engineering permits us to believe that the day when the first flights into cosmic space become reality is not far distant. The World Astronautical Federation already embraces twenty-three countries. The Interdepartmental Commission for the Coordination and Performance of Interplanetary Communications of the USSR Academy of Sciences is a member of that Federation. Rocket and interplanetary societies, whose members include specialists, enthusiasts, and simply persons interested in astronautics, have been organized in many countries to attract attention to and stimulate support of cosmic flights.

In the Soviet Union, an astronautics section has been established at the Chkalov Central Aviation Club of the USSR in Moscow. Sections and circles are being organized in other cities on this pattern. Today, interplanetary flight enthusiasts are taking active part in the International Geophysical Year, which will last from 1 July 1957 to 31 December 1958. In the course of this year, the launching of a number of experimental rockets into the upper layers of the atmosphere, and of the first chemical-fuel earth satellites, is projected. The launching in

the USSR, in August 1957, of a superlong-range ballistic rocket and, in October 1957, of the world's first artificial satellite, marked a significant step in the development of science and engineering in our country, and in the strengthening of the defense capability of the USSR.

The perspectives before science are limitless. There can be no doubt of the fact that, with the passage of time, these complex problems will be solved, and man will master interplanetary flight exactly as he has mastered flight in the atmosphere surrounding the earth.

Conclusions

The question as to the necessity and possibility of applying atomic energy in aviation has already been given a positive answer and solution. This is primarily demonstrated in the directives of the Twentieth Congress of the Communist Party of the Soviet Union, which indicate the need to develop atomic engines for transport purposes.

The development of atomic aircraft engines is also moving forward on a broad front in other countries. Each day the press carries new data on the development of projects of atomic aircraft, on the development of the first atomic aircraft engines using nuclear fuel, etc. The majority of foreign scientists believe that the first flights by atomic aircraft may be expected in 1959 - 1960. Time will show how accurate these prophecies are.

Much has already been done in the field of applying atomic energy to military, industrial, and transport purposes. But considerably more remains to be done.

The solution of the problem of applying atomic energy in aircraft power plants will require extensive scientific studies, engineering and technical developments, and experiments. The designing of atomic engines and aircraft, experimental work on aircraft reactors on the ground and in the air, the search for new structural materials, methods and means of radiation shielding - these are the main trends

along which this work will proceed.

Successful solution of the problems of producing atomic engines for aviation will constitute a new giant step forward in the progress of aircraft science and engineering.

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Appendix E

The Library of Congress,
Reference Department,
Science and Technology Division,
Washington, D.C., February 20, 1959.

Joint Committee on Atomic Energy,
Room F88, Capitol,
Washington, D.C.

Dear Sir: Your telephone request of February 16 to our Legislative Reference Service concerning a bibliography on the atomic aircraft propulsion program was referred to this Division.

Enclosed is a selected listing of references which we believe to be of pertinence to your request. Copies of any of these publications should be requested from the Loan Division of the Library of Congress.

If we can be of further assistance please let us know.

Very truly yours,

John Sherrod,
Chief, Science and Technology Division.

Enclosure: Bibliography.

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